

7TH INTERNATIONAL RAINWATER CATCHMENT SYSTEMS CONFERENCE
June 21-25, 1995, Beijing, China

RAINWATER UTILIZATION FOR THE WORLD'S PEOPLE

PROCEEDINGS

Volume 1



Canada



IRCSA
Japan

Section 1

COMPREHENSIVE STUDY

7th International Rainwater Catchment Systems Conference
(7th IRCSC)

RAINWATER UTILIZATION FOR THE WORLD'S PEOPLE

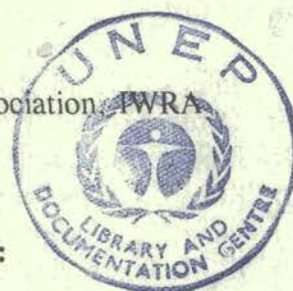
*Venue: Beijing International Convention Centre
21-25th June, 1995 Beijing, China*

ORGANIZED BY:

The Geographical Society of China, Hydrologic Committee
United Research Centre for Water Problems, Chinese Academy of Sciences
The Water Conservancy Society of China, Water Resources Committee

IN COOPERATION WITH:

International Rainwater Catchment Systems Association (IWRA)



DONORS AND SUPPORTERS:

United Nation Environmental Program
International Rainwater Catchment Systems Association-Japan
Swedish International Development Agency
Canadian International Development Agency
National Natural Sciences Foundation of China
Chinese Academy of Sciences

ORGANIZING COMMITTEE

Honorable Chairman: **Ya-feng Shi** and **Shu-peng Chen**

Chairman: **Chang-ming Liu**

Vice-Chairmen: **Jia-zhen Zhang** and **Ze-zhen Zhang**

Secretary General: **Hai-sheng Mou**

Assistant Secretary General: **Guo-you Zhang** and **Tian-wen Cheng**

INTERNATIONAL/LOCAL STEERING COMMITTEE MEMBERS

- | | |
|-------------------------------------|------------------------------|
| Prof. Yu-si Fok, President(U.S.A.) | Prof. Bing-wei Huang(China) |
| Dr. Adhityan Appan(Singapore) | Prof. Shu-peng Chen(China) |
| Prof. Shou-Chyuan Zhu(Taiwan) | Prof. Ya-feng Shi(China) |
| Dr. Hari J. Krishna(U.S.A.) | Prof. Yuan-chun Shi(China) |
| Dr. John Skoda(Fiji) | Prof. Hong-lie Sun(China) |
| Mr. Nik Fuaad Nik Abllah(Malaysia) | Prof. Guan-hua Xu(China) |
| Prof. Andrew Lo(U.S.A.) | Prof. Yu-qing Wang(China) |
| Dr. Joao Gnadlinger(Brazil) | Prof. Er-jin Cheng(China) |
| Dr. Wanpen Wirojanagud(Thailand) | Prof. Lan-sheng Zhang(China) |
| Dr. R. Heggen(U.S.A.) | Prof. Guang-zhao Ren(China) |
| Mr. J. T. Visscher(The Netherlands) | Prof. De-sheng Jiao(China) |
| Mr. Ahang Kowsar(Iran) | Prof. Wei-jun Cheng(China) |
| Mr. A.T. Amuzu(Ghana) | Prof. Gai Yin(China) |
| Prof. Isao Minami(Japan) | Prof. Gan-qing Shen(China) |
| Mr. Makato Murase(Japan) | Prof. Fu-chen Ma(China) |
| Mr. C. Villareal(Philippines) | Prof. Jin-ning Zhu(China) |
| Mr. John E. Gould(U.K.) | Prof. Ya-zhou Lu(China) |
| Mr. Lorena Aquilar(Costa Rica) | Prof. Bo-ren Guan(China) |
| Dr. J. Salas(Philippines) | Prof. Shi-bo Hui(China) |
| Dr. Robert S. Schemenauer(Canada) | Prof. Xi-wu He(China) |
| Dr. Jamal Ghoddousi(Iran) | Prof. Wei-cheng He(China) |
| Dr. G. K. Bambrab(Kenya) | Prof. Ke-jiang Cai(China) |
| Mr. John La Roche(New Zealand) | Prof. Ke-xin Cheng(China) |
| Dr. Uzir Bin Abdul Malik(Malaysia) | Prof. Yue-xian Xu(China) |
| Prof. Alan A. Fewkes(U.K.) | Prof. Mei-hua Ling(China) |
| Dr. Donald H. Waller(Canada) | Prof. Ming-yue Luo(China) |
| Dr. David N. Holmes(Venezulia) | Prof. Yong-mao Liu(China) |
| Mr. John Mbugua(Kenya) | Prof. Yun-long Cai(China) |
| Prof. Pilar Cereceda(Chile) | Prof. Yu-kai Liu(China) |

PREFACE

Rainwater utilization has had a history of several thousand years and it will soon be seen as a prosperous way to solve water shortage problems in the coming century. Based on the development of rainwater utilization, the connotation of rainwater resources and its catchment systems have been become much more widely extending towards sustainable water exploitation since the establishment of the International Rainwater Catchment Systems Association in 1983 in Hawaii. Rainwater can be used in both direct and indirect ways because rainfall transforms into different hydrological states with diversified patterns of water interactions. For instance, roof catchment systems represent the direct collection of rainwater, while ponds or reservoirs can receive water indirectly from surface runoff and subsurface flow as so-called direct runoff and inter-flow resulting from a rainfall within a given catchment. The extended connotation of rainwater utilization can also include artificial recharge of shallow groundwater by using rainfall in terms of building up a groundwater reservoir for pumping wells and a soil water reservoir for agricultural production. In addition, a new idea of rainwater collection may concern weather modification, i.e. artificial rain. Therefore, the substantiation of the concept of rainwater resources and elaboration of the connotation concern a broader prospect of rainwater utilization. In this context, it is expected that the rainwater catchment systems may be turned into an independent branch of water sciences.

During the 6th International Rainwater Catchment Systems Conference held in August, 1993, in Nairobi, Kenya, the International Rainwater Catchment Systems Association decided to hold its 7th International Conference in Beijing and suggested that we form the Local Organizing Committee to carry out the preparation for the Conference. It was my great pleasure to have this opportunity to promote the study of rainwater resources and its utilization.

During the past two years we have worked under the direction of the International Rainwater Catchment Systems Association and have made great progress. The Organizing Committee has received over 200 abstracts of papers and posters from 41 countries or regions, and about 130 full papers from more than 30 countries or regions. These papers concern each aspect of rainwater utilization, including comprehensive research, social and economical development, full utilization of rainwater for all the sectors such as urban, industry and agriculture, effects on ecology and environment, exploring the role of women in rainwater utilization, techniques of rainwater collection, water quality and its protection, study methodology and modelling. These abstracts and full papers are bound separately into three volumes with a total of more than 1400 pages, reaching an unprecedented scale.

The substantial support for the preparation work on this conference has come from the various organizations and academic institutions both at home and abroad. Thus, on behalf of the Local Organizing Committee, I heartily wish to thank all sponsors, co-sponsors, and the staffs working on the conference. We will make further efforts to edit and to publish the proceedings formally after the Conference. We hope the achievements obtained from this conference will further the theory and practice of rainwater utilization both in China and in the world.

Changming Liu

Chairman, Local Organizing Committee

Editing Group of the Proceedings of 7th IRCS Conference:

Haisheng Mou and (Ms) Huilin Wang

Dept. of Geography, Beijing University

Guoyou Zhang, Ting Ni and (Ms) Anli Yu

Geographical Society of China

Yanchun Gao, (Ms) Lijuan Li and (Ms) Yunmei Ma

Dept. of Hydrology, Institute of Geography, CAS

CONTENTS

COMPREHENSIVE STUDY

The Role of RWCS in 21st Century Water Management	1-1
<i>Yu-si Fok, U.S.A.</i>	
Rainwater Catchment Systems Context	1-5
<i>Changming Liu, Haisheng Mou, China</i>	
Rainwater Catchment and Utilization in the Arid and Semi-arid Area in Gansu, China	1-18
<i>Zhu Qiang and Wu Fuxue, China</i>	
Why Not Harvest Rain?	1-28
<i>J.E. Chagomelana, Malawi</i>	
Rainfall and its Utilization in the Central Arid Region of Gansu Province	1-31
<i>Gong Xiaohu, China</i>	
Weather Modification as a Water Resource Shortage Solution in Heilongjiang: Possibility and Applicability.....	1-40
<i>Jin Ying, China</i>	
Construction of Plain Drainage System for a Good Use of Rainwater	1-51
<i>Baohong Lu, Kailin Wang, Kejian Cai, China</i>	
Technical Development of Rainwater Catchment Systems	1-58
<i>Isao Minami, Japan</i>	

SOCIO-ECONOMIC CONCERN

Socio-economic Aspects of Rainwater Catchment Systems Utilization: the Developing World Perspective . . .	2-1
<i>Darius G. Rutashobya, Tanzania</i>	
Flood Migration and Water Harvesting: Benefits from Rainwater Utilization	2-10
<i>Luo Ching-Ruey and Ju Yih-zeng, Taiwan</i>	
Indigenous Rainwater Harvesting Systems in Sri Lanka: Current Status and an Eco-system Approach to Revitalization	2-17
<i>C.M. Wijayarathna and A.S. Widanapathirana, Sri Lanka</i>	
The Coordinate Growth Between the Development of Water Resources and Social Economics in Dalian . . .	2-33
<i>Luan Weixin, China</i>	
Community Involvement in the Construction of Ferrocement Rainwater Tanks --- The Case of Maswa District	2-40
<i>E.J. Chaggu, Tanzania</i>	
An Analysis on the Effects of Building the Ponds for Gathering Rainfall on the Upper Reaches of the Huaihe River	2-51
<i>Guan Hua, Zhao Bingdong and Shi Zhaoli, China</i>	
The Present Status and Future Prospects of Rainwater Catchment Systems in Taiwan	2-59
<i>S.C. Chu, K.F. Andrew Lo and C.H. Liaw, Taiwan</i>	
Rainwater Harvesting Project for Bounavista	2-68
<i>Lakshman Welikala, Sri Lanka</i>	
Analysis of Economic Benefit Generated Due to Groundwater Recharge by Rainwater Interception in North China	2-74
<i>Yan Zhenyuan, China</i>	
Community Participation in Water Harvesting Experiences and Lessons from Homabay District	

Nyanza Province, Kenya	2-83
<i>Johnson Akoko Ouko, Kenya</i>	
Rational Exploitation and Utilization of Water Resource in Heilongjiang Province	2-91
<i>Zhang Guilan and Zhang Xuqiang, China</i>	

ECOLOGIC AND ENVIRONMENTAL ASPECTS

Effect of Rainwater Reuse on Ecological Environment in Shiyang River Catchment	3-1
<i>Jiong-lin Shi, China</i>	
Technological Development, Rainwater Utilization, Ecological Changes and Environmental Degradation in the Drylands of East Africa	3-8
<i>J.P. Msangi, Kenya</i>	
Environmental Issues in Rain Water Catchment System	3-20
<i>S. H. C. De Silva, Sri Lanka.</i>	
Endfield Research on Rainfall Utilization for Water and Soil Conservation at Soil and Water Loss Region in Zhalantun, China	3-26
<i>Mao Minghai, China</i>	
Fog Drip in California and its Implications for Cisterns	3-36
<i>Robert J. Kourik, U.S.A.</i>	
Environmental Contributions of Some Traditional Techniques	3-51
<i>Nirmal Sengupta, India</i>	
Studies on the Changing Tilting Angle of Solar Array in Rainwater Utilization System	3-61
<i>Mitsuo IDE, Kouichi Takeyama, Akira Higuchi, Kenzo Ohara and Hikaru Tsutsui, Japan</i>	
Building Rainwater Harvesting System to Protect Environment and Develop Production in Helan Mountain	3-71
<i>Weinong Liu, China</i>	
Relationship among Acid Precipitation and Meteorological Factors	3-76
<i>Wang Xirong, Zheng Deqing and Wang Hongxing, China</i>	
Impact of Environmental Changes in Rainfall Pattern and Aridity in Eastern-sudan	3-82
<i>Shamsul Haque Alvi and Nadir Ahmed Elagib, Bahrain</i>	
Preliminary Analysis of the use of the rainwater in Hebei Province.	3-98
<i>Yu Fenglan, China</i>	

NATIONAL OR REGIONAL EXPERIENCES

Rainwater Utilization in Semi-arid Hilly Region of North China--a Case Study from Yuanshi County of Hebei Province	4-1
<i>Wu Jingtang, Haisheng Mou, China</i>	
Rainwater Catchment Systems in Texas	4-13
<i>J. Hari Krishna, U.S.A.</i>	
Research on the Current Situation and Strategy for Development of Rainwater Utilization in Jiaodong Peninsula	4-18
<i>Jiang Chenguang, Yuan Chungqiao, China</i>	
An Overview to the Development and Use of Rainwater Harvesting Systems in Iran	4-26
<i>Jamal Ghoddousi, Iran</i>	
Rainfall Utilization in the Islands of Haizhou Bay	4-37
<i>Liang Haitang, China</i>	

Development in Rainwater Catchment Systems in Eastern and Southern Africa	4-44
<i>John Gould, Botswana</i>	
Indigenous Irrigation Systems and Resource Mobilization for Utilizing Rain Water: A Lesson from the Hills of Nepal	4-56
<i>K. R. Adhikari, Nepal</i>	
Water Available in the Karstic Reef Limestone Area	4-72
<i>Sunjoto Sun, Indonesia</i>	
The Present Utility of Rainfall in South Part of Ningxia and the Prospect for Development	4-77
<i>Yu Junling, China</i>	
Rainwater Harvesting and Storage Techniques from Bangladesh	4-82
<i>Abutaher Md. Ziauddin, Bangladesh</i>	
Explosion and Utilization of Rainwater Resources on Arid Area in Gansu Province	4-94
<i>Tian Yuan, Su Yongxin, China</i>	
Development on Rain-fed Agriculture of Delta of Wide Area in Asia	4-100
<i>Isao Minami, Ichiro Kita, Nobuo Kanamori, Chizuko Fukami, Japan; Vuong Bach Tuyet, Vietnam and Saiful Rochdyant, Indonesia</i>	
Current State of Rainwater Utilization in Terraing Agriculture and Its Development in Gansu, China.	4-110
<i>Zhen Baosu, China</i>	
Research of Flood Rainwater utilization in Beijing Municipality	4-117
<i>Hui Shibo, China</i>	

DOMESTIC SECTOR

Courtyard Model of Catchment and Storage Water in the Arid Areas	5-1
<i>Yang Xijin, Zhang Xingyou and Wu Huairong, China</i>	
The Catchment and Utilization of Yard Rainwater in Zhuanyaogou Valley	5-10
<i>Li Hongjian and Liang Si, China</i>	
Rainfall Collection to Develop Courtyard Economy	5-15
<i>Wang Wenyuan, Yang Luhua & Zhao Lianying, China</i>	
Improved Roof Rainwater Harvesting in primary Schools	5-19
<i>Niemi Tapio, Finland</i>	
The Rain Water Harvesting System and the Development of Courtyard Economy	5-34
<i>Wanjin Zhang, Yonghui Yang, China</i>	
Water Cellar ---- Safe, Convenient and Cost-effective	5-41
<i>Zhang Chaoyang, Ge Maohang and Song Wei, Wang Yongsheng, China</i>	
Rainwater Harvesting for Buonavista Galle - Sri Lanka by the Church of Ceylon Board of Women's Work and the Archdeacon of Galle	5-49
<i>Jessica Alles, Sri Lanka.</i>	
Rainwater Use in Livestock Farming and Gardening	5-55
<i>M.d. Daulat Hussain, Bangladesh</i>	
Building Pond for Harvesting Hillside Rainwater: an Effective Solution to the Problem of Drinking Water Supply	5-64
<i>Tang Kuisheng, Liu Fuying, Tan Shiqing, China</i>	
Roof Rainwater Harvesting System in Changdao County and Analysis on its Ecological Benefits.	5-75
<i>Sun Fuwen, Zhou Qiyun and Liu Yulu, China</i>	

AGRICULTURAL SECTOR

✓ Cisterns for Rural Low Income Communities in Northeast Brazil	6-1
<i>Johann Gnadlinger, Brazil</i>	
Perspective of Rain-fed Agriculture's Development in Guantao County	6-11
<i>Zhongsheng Zhou, Xingji Li and Yuanliang Lang, China</i>	
Comprehensive Utilization and Administration of Water Resources of Zhang-fu-he Irrigation Area	6-21
<i>Zhao Haisen, China</i>	
The Effect on Rainfall Catchment and Use of Sowing in Furrow (Sif) on Rain Fed Crop	6-26
<i>Liu Yi and Qian Dabin, China</i>	
Agriculture Rainwater Catchment Systems in Mudstone Areas of Kaohsiung, Taiwan	6-29
<i>S.C. Chu, C.H. Liaw and W.L. Hwang, Taiwan</i>	
✓ The Repetitive Irrigation Systems Used in Ouchi, Ishikawa Prefecture, Japan	6-40
<i>Kunihiko Kitamura and Ichiro Kita, Japan</i>	
High-density Fish-farming Using Warm Water Discharged from Power Plant: ---Discussion on Rain Water Reuse	6-45
<i>Shao Xiaozhi, Shao Hua, China</i>	
Soil Water Conservation Practices and Their Research Advances in Northern China	6-48
<i>Cao Jianru and Zhang Guangrong, China</i>	
The Way to Improve Water Use Efficiency on Rainfed Area	6-55
<i>Wang Youzeng, Chen Fengrui, China</i>	
Using the Rain Water Resource to Promote the Development of Agriculture and Animal Husbandry	6-60
<i>Zhang Junmin and Yuan Huibing, China</i>	
Impact of Wheat Straw Mulch on Utilization of Rain and Snow Resources in Arid Land of China	6-65
<i>Pei Liyun, China</i>	
Researches on Rain Conservation Measure for Unirrigated Date Trees	6-71
<i>Wang Qinghe, China</i>	
Countermeasures of Development of Rainfed Agriculture in Hilly Area of Qinghai province	6-76
<i>Yang Xueliang, China</i>	
✓ The Development of Rainwater Catchment System for Paddy Irrigation In the Muda Irrigation Scheme, Malaysia: a Case Study Of In-site Rainwater Harvesting	6-81
<i>Uzir Abdul Malik and Ir. Sardar Ali, Malaysia</i>	
Increasing the Rainfall Effective Utilization Ratio by Making Full Use of Forecasts on Meteorology and Soil Moisture Content	6-100
<i>Yang Luhua, Wang Wenyuan, China</i>	
The Exploitation of Rainfed Agricultural Region	6-105
<i>Zhang Zitai, Guo Songniang, China</i>	
Practices on the Rain Fed Land Agricultural Development in Heilonggang Area of Hebei Province	6-109
<i>Qu Shengli, China</i>	
A New Technology for the Effective Utilization of Rain in Agriculture	6-113
<i>Chi Jiujian, Yan Shuxiang, Zhao Heyu, China</i>	
Studies on the Optimal Development of Paddy Field in Songhuajiang Prefecture, Heilongjiang	6-123
<i>Li Hengshi, Lan Yuping, Liu Xudong, Ren Yudong and Qu Mingcai, China</i>	
Spacial Characteristic and Related Techniques of Rainwater Utilization for Dry-land Wheat	6-126
<i>Zhao Xuetao, China</i>	

'Bao Lou' Irrigation of Paddy Field to Promote, Rainwater Use Efficiency	6-136
<i>Yi Yongqing, China</i>	

The Transformation of Inferior Soil by Rain Water	6-142
<i>Xiangqin Xiao, China</i>	

RAINWATER UTILIZATION IN URBAN AREAS

Integrated Water Management for Urban Areas	7-1
<i>Wolfgang F. Geiger, Germany</i>	

Studies on Rainfall Runoff Utilization in Urban Area in Beijing	7-22
<i>Chong Yuqi, Zhang Weihua and Duan Wei, China</i>	

Study on Making Use of Rain Water in City Afforestation	7-29
<i>Guo Songnian and Zhang Zitai, China</i>	

Onsite Storage of Stormwater Runoff for Flood Control	7-32
<i>Michael Boyd, Australia</i>	

A Report of a Rainwater Catchment System in a Golf Driving Range	7-41
<i>Kevin Lim Chiow Teck, Malaysia</i>	

Rainwater Utilization and Spring Conservation in Jinan	7-46
<i>Han Hongnuan, Zhuang Huibo, China</i>	

A Total Approach Towards the Design of RWCS in Airports Subjected to Tidal Effects	7-51
<i>Appan A., T. Jeyaprakasham and S. Punithan, Singapore</i>	

Strategic Options for Rainwater Harvesting Activities in Sub-Sahara Africa	7-61
<i>G.K. Bambrah, Kenya and F.O. Otieno, South Africa.</i>	

WOMEN ACTIVITIES IN RAINWATER USE

Women Issues in Rainwater Collection Projects	8-1
<i>Jessica Calfoforo Salas, Philippines</i>	

Present Situation and Potential Development of Women's Role in Rainfed Farming: a Rural Survey in Hebei Lowland Plain	8-7
<i>Ma Jingmin, Li Zhihong, Li Kejiang and Qu Shengli, China</i>	

Role of Women in Water and Sanitation Development	8-11
<i>John M. Erskine, South Africa</i>	

The Role of Women in Roof Catchment Water Tank Projects in the Catholic Diocese of Nakuru, Kenya ...	8-21
<i>Tarcisius G. Kingori, Kenya</i>	

A Strategy to Introduce Rainwater Collection among the Urban Low Income Settlement's of Bangladesh ...	8-26
<i>Salma A. Shafi, Bangladesh</i>	

Investigated Report on the Rain-water Convergency Techniques in Central Hunan of China	8-31
<i>Jiang Tiebing, Tang Jiuru, Kang Ling, Yu Jinjiang, China</i>	

RAINWATER QUALITY AND ITS PROTECTION

The Water Quality Problem of Rainwater Utilization in the Arid Region of Northwest China	9-1
<i>Yang Xijing, Zhu Hong, Zhang Xingyou, China</i>	

Rainwater Catchment System in Central Region of Benin (West- Africa), Water Pollution and Environment Safeguard	9-15
<i>Houssou Christophe Segbe, Benin</i>	

Fluctuation of the Quality of Container-stored Rainwater During Storage	9-27
<i>Ichiro Kita and Kunihiro Kitamura, Japan</i>	
Potabilization of Rainwater	9-33
<i>Otto F. Joklik, Austria</i>	
A Solar Powered UV System to Disinfect Cistern Waters	9-48
<i>Roger Fujioka, Geeta Rijal, U.S.A. And Bo Ling, China</i>	
A Homeowners Test for Bacteria in Cistern Waters	9-58
<i>Geeta Rijal and Roger Fujioka, USA</i>	
Rainwater Roof Catchment Systems for Domestic Water Supply in South of West Bank	9-65
<i>Abu-sharekh, West Bank/Israel</i>	
Cisterns Water Quality in South of West Bank	9-77
<i>Abu-sharekh and Y.M. Subuh, West Bank/Israel</i>	
Water Quality Issues in Rainwater Cistern System in Some South East Asian Countries	9-91
<i>Adhityan Appan, Singapore</i>	
Prospect of Rainwater Catchment in Bangladesh and its Utilization	9-102
<i>Amin Uddin Ahmad, Bangladesh</i>	
Rates and Chemical Analysis of Occult Precipitation	9-110
<i>Elias V., Tesar M., Czech Republic</i>	
A Preliminary Study of Pellet-type Purifier	9-120
<i>Wang Yongsheng, Li Peihong, Yan Dakao and Zhang Kefeng, China</i>	
Catchment Water to Public Health Standards	9-128
<i>H.E. Finch, USA</i>	

TECHNIQUES AND DESIGNING

The Field Testing of a Rainwater Collector	10-1
<i>Alan Fewkes, United Kingdom</i>	
Study on the Roof Water Collection Project Improvement Measurement	10-11
<i>Han Guangen, Cai Jianmin and Li Xiuyun, China</i>	
Experimental Researches on Utilization Rainfall to Recharge Underground Water at Yanzhou County, Shandong Province	10-19
<i>Wang Shoumin, Wang Yi, China</i>	
Use of Porous Pavements for Water Storage	10-28
<i>C. J. Pratt, UK</i>	
Rain Water Cistern Systems: a Regional Approach to Cistern Sizing in Nova Scotia	10-38
<i>R.S. Scott, J.D. Mooers and D.H. Waller, Canada</i>	
Performance of an Instrumented Roof Catchment System in Botswana	10-49
<i>A. Gieske, J. Gould and F.t.k. Sefe, Botswana</i>	
Simple Model for Rain Harvesting Systems Designing	10-60
<i>Jure Margeta, Croatia</i>	
Design Strategies for Rainwater Collectors	10-70
<i>Kwong Fai Andrew Lo, USA</i>	
Sand Buried Membrane Technique for Rainwater Harvesting in Arid and Semi-arid Lands	10-82
<i>R.K. Muni, Kenya</i>	
Research of Roof Rainwater Collection for Drinking in Coastal Area	10-88

<i>Yang Xiukun, Li Guilin, China</i>	
✓ Improving a Kind of Water Harvesting System in North-east Iran	10-94
<i>Ali Akbar Abbassi, Iran</i>	
Guttering: Barrier to the Effectiveness of Rainwater Catchment Systems in Developing Countries	10-101
<i>James Mwami, Uganda</i>	
Experiment Study of Storm-water Drainage Pipes of Infiltration Type	10-108
<i>Wang Wenyuan, Ji Guixia, China</i>	
Rainwater Utilization in Izumo Dome & Some Reformatons for Automatic Rainwater Catchment System ...	10-113
<i>Kouichi Takeyama and Isao Minami, Japan</i>	
Analysis of Planning, design and construction of Rainwater utilization Pattern and Effect in Hula Mountain Grassland of Xinjiang.	10-121
<i>Han Xiankun, China</i>	

METHODOLOGY AND MODELING

Rainfall Intensity and Rainwater Catchment	11-1
<i>Richard J. Heggen, USA</i>	
A Model for System Making Use of Rain Arid Area	11-6
<i>Chen Zhongquan, Liu Puxing, Zhang Zhendong and Chang Hong, China</i>	
Spatially Varied Flow over a Side Weir in a Rectangular Channel	11-10
<i>P.W. France, UK</i>	
Characteristics and Design Criteria of Gutter Snipe	11-18
<i>Luo, Ching-ruey, Taiwan</i>	
Analysis of Rainfall as a Design Parameter for Rainwater Catchment Systems	11-30
<i>Ngigi, S.N., Kenya</i>	
Effective Rainwater Model for Upland Crop Irrigation	11-41
<i>Charles C.C. Shih, Taiwan</i>	
A Preliminary Research on Alfalfa Water Consumption and Rainfall Utilization	11-55
<i>Wang Xinyuan, Yin Yanfeng, Zhang Xiying and Mao Xuesen, China</i>	

THE ROLE OF RWCS IN 21ST CENTURY WATER MANAGEMENT

Yu-Si Fok*

Abstract: Rainwater catchment systems (RWCS) are age-old water supply systems that will regain their position in diverse forms to complement centralized public water systems in the 21st century. Regardless of the level of development, many public water supply systems have already shown their inability to expand fast enough to meet the ever-increasing demand for water. As a result, water management decision makers have made efforts to find complementary ways of providing and conserving water. RWCS stands out as a practical solution. Users could develop their own RWCS to become self-sufficient in water, or at least to alleviate water shortage impacts. This paper explores the role of RWCS in 21st century water management with viewpoints from the public and private sectors reflecting social, economic, environmental, and institutional concerns. Also, this paper proposes the integration of RWCS with other renewable resource collection systems in designing new sustainable structures for the 21st century.

INTRODUCTION

Rainwater catchment systems (RWCS) are age-old water supply systems which have been widely used all over the world. However, many of them were replaced by efficient, convenient, and dependable centralized public water supply systems after the industrial revolution. In recent decades, the situation has changed because most of the public water supply systems are not able to expand fast enough to meet the ever-increasing demand for water in urban areas. As a consequence, decision makers in water management are already looking for complementary ways of providing and conserving water.

RWCS have been rediscovered as a practical means of providing water for users at their doorsteps (Fok 1982). Because rooftops and/or neighboring areas can be utilized to catch rainwater, the only need is for a storage tank, which can be constructed and financed by the users themselves.

This paper presents the role of RWCS in 21st century water management with viewpoints from the public and private sectors reflecting social, economic, environmental, and institutional concerns. In addition, this paper proposes the integration of RWCS with other renewable resource collection systems in designing new sustainable structures for the 21st century.

SOCIAL CONCERNS

Before the industrial revolution, domestic water supply systems, such as shallow wells and rainwater cisterns, were mostly privately owned; the general public had to fetch water from wells, ponds, streams, and springs. Fetching water is still practiced in many parts of the world, especially in rural areas. However, because valuable time and energy are wasted on water fetching and because oftentimes fetched waters are taken from polluted sources, social and health problems arise. These problems can be alleviated with the use of RWCS at individual residences where stored rainwater can be kept and maintained free of contamination.

The major objective for the United Nations' International Drinking Water Supply and Sanitation Decade (1981-1990) was to provide safe drinking water and sanitation conditions for users. Once a country's public health is upgraded, its national productivity increases. Ultimately, the whole nation's social well-being can be improved. RWCS are expected to play an important role in the social well-being of a country in the 21st century because they can be developed and operated with appropriate technology by the users. The Thailand jar program—as reported by Sethaputra (1986), Wirojanagud and Chindaprasit (1987), and Fok (1989)—is an excellent example of a governmental policy to provide drinking water to the rural population and hence improve the country's social well being. Its jar program made Thailand the only country to fulfill the United Nations' goal for the International Drinking Water Supply and Sanitation Decade by

*Professor, Department of Civil Engineering and Researcher, Water Resources Research Center, University of Hawaii at Manoa, 2540 Dole Street, Honolulu, Hawaii 96822-2333, U.S.A.

providing safe drinking water to its rural population by the end of 1990. Thailand's rural population is comprised of 18 million people.

ECONOMICAL CONCERNS

According to Fok and Leung (1982), the cost analysis of RWCS related a wide range of unit costs for storage tanks made with different construction materials. As reported, the per-cubic-meter storage capacity cost from \$10 (all dollar amounts in this paper in U.S. dollars) for a ferroconcrete Thai jar to \$300 for a red wood tank. The construction cost for each unit of a public water supply system may be lower than that of an RWCS made with the cheapest material (such as the Thai jar), but if the costs for water delivery, rights of way, environmental damage, and water rights are included in the total for the public water supply system, the unit cost for the private system becomes comparable to the unit cost for the public system. For example, the current development cost for a system deriving water from a groundwater source in Honolulu, Hawaii, U.S.A., is about \$2 million for 0.04 m³/s (1 million gallons per day), not including the costs of pumping and hookup with an existing pipeline. Currently, Honolulu water users are charged about \$1.06 per cubic meter of water (1/3 for water cost, 2/3 for wastewater treatment). The low cost is due to the fact that the vast water supply systems owned and operated by the City and County of Honolulu Board of Water Supply have been well managed for decades and most of its long-term mortgages have been paid off. Therefore, even though unit water development costs are high at present, expansion of the capacity of the public water supply system can be accomplished without resulting in a higher water bill for users.

Because RWCS in general are privately owned, they lessen the financial burden on the public sector. The Thailand Jar Program is a good example of the success of a well-planned national policy. The Thai government spent only \$7.4 million dollars to induce investments of \$180 million from the private sector to construct 9 million 2-m³ jars to provide drinking water to more than 18 million rural inhabitants from 1983 to 1986 (Fok 1993). This breaks down to a cost of \$10.41 per person. From the above analyses, it can be concluded that RWCS development can have a very positive role on the national economy because it only costs about one-tenth of the World Bank's estimated \$100 per-capita drinking water development cost of \$100 (Fok 1989).

ENVIRONMENTAL CONCERNS

The world's metropolises—such as Beijing, Los Angeles, New York, Rome, and Tokyo—use centralized public water supply systems to provide water to users from reservoirs located more than 100 km away. They spent large sums to construct dams and water-transport lines to support these systems. However, because these systems cause great environmental impacts, have reached their expansion limit, and could be destroyed or damaged by natural disasters (such as an earthquake), the metropolises have begun to look for viable alternative (or complementary) water supply systems that promote water conservation and environmental protection (Tokyo conference proceedings 1994).

RWCS are diversely developed; they are located where the users live and are built to exist in harmony with the environment on a relatively small scale or as part of an existing structure. Also, they can provide water for landscaping. Users will practice water conservation because, as managers of the RWCS, it is only natural that they will want to maintain water in their storage tank. These are positive ways the RWCS can have an impact on the environment. Other positive uses for the RWCS include providing emergency water for drinking and fire fighting and providing a supplementary water supply.

From the standpoint of public water supply decision makers, the RWCS' environmental role alone is adequate for them to recommend it as a viable alternative to the public water supply system in their 21st century water management plan.

INSTITUTIONAL CONCERNS

Public-sector water decision makers are familiar with aspects of water resources planning, development, and management. They consider it their responsibility to provide water to the general

public. However, they are not prepared for the existence of privately owned RWCS outside of their domain. Perhaps they even consider RWCS development a threat to their jobs—because if most of their water customers develop RWCS, the public water supply systems would have to be scaled down or closed down. Although this situation is not likely to happen, the possibility does exist. This feeling is common among the decision makers of local public water supply and public works agencies. Their view of RWCS users as outlaws can be felt when private citizens request their help in getting the required building permit or just ask for their advice on RWCS planning, development, or management. Oftentimes, institutional constraints are imposed due to the lack of guidelines for development. However, even when public-sector water decision makers are supportive of RWCS development, without the needed guidelines they cannot offer any help for RWCS construction based on existing regulations for building permits.

The problems resulting from the lack of RWCS guidelines have received lawmakers' attention. In 1994, the House of Representatives of the State of Hawaii issued House Concurrent Resolution No. 214, requesting that the University of Hawaii Water Resources Research Center develop guidelines which may be adopted by county planning and building departments to control the construction of private water catchment facilities. The author of this paper was requested to develop guidelines that would include the following items:

- (1) The required roof catchment area and size of water storage area in conjunction with the living area and average rainfall in the geographic area considered
- (2) The nature of building materials that rainwater will come in contact with during collection, storage, and distribution
- (3) Recommended filter systems
- (4) Requirements that everyone's water be available to the proper authorities in the case of fire or other natural disaster
- (5) A method to guarantee that a specific number of gallons of water is always available for fire fighting purposes
- (6) A recommended maintenance program for homeowners to follow, such as changing filters and cleaning roofs and gutters

Once the guidelines are adopted, RWCS development in the 21st century is likely to have the blessing of public-sector water decision makers. RWCS will be considered as one means of sustaining water resources that can be developed and operated by the private sector.

INTEGRATING RWCS WITH OTHER RENEWABLE RESOURCE COLLECTING SYSTEMS

According to Fok (1992), rooftops should be utilized not only to collect rainwater but also to collect energy. He pointed out that advances in technology have made his proposition a reality. He reported that rooftops are underutilized resources; to more fully use rooftops, at least five natural resource collection systems can be installed, namely:

- (1) Rainwater catchment
- (2) Solar water heater
- (3) Solar electricity panel (photovoltaic panel)
- (4) Wind mill
- (5) Drying pan

Fok (1992) proposed that new buildings in the 21st century be self-sufficient in energy and water. He pointed out that if sufficient energy can be collected, wastewater and waste generated within the building can be treated for recycling or reuse.

CONCLUSIONS

This itemized study of RWCS development—reflecting social, economic, environmental, and institutional concerns—help to qualify RWCS as a suitable alternative for 21st century water management. Proper guidelines should be developed so that public-sector water management decision makers can consider RWCS as a viable alternative or complementary water supply source for the 21st century.

RWCS are privately owned, developed, and operated and are quite different from centralized public water supply systems. Guidelines for RWCS construction and maintenance should be developed so that proper building permits can be issued.

RWCS should be integrated with other renewable resource collection systems in designing 21st century buildings that are self-sufficient in energy and water. When sufficient energy can be collected, the wastewater and waste of each building can be treated for reuse or recycling to qualify the 21st century buildings as structures which are sustainable in utilities.

ACKNOWLEDGMENTS

The author thanks the Water Resources Research Center publications staff for preparing this paper in camera-ready form. The work upon which this paper is based was supported in part by the Water Resources Research Center, University of Hawaii at Manoa, in response to House Concurrent Resolution No. 214. This is WRRRC contributed paper CP-95-06. The writer also thanks the 7th International Rainwater Catchment Systems Conference's Organizing Committee for inviting him to present this paper as one of the keynote papers at the conference.

REFERENCES CITED

- Fok, Y.-S. 1989. The international drinking water supply and sanitation decade (1981-1990) and the progresses of rain water cistern systems. Proc. 4th Int. Conf. on Rain Water Cistern Systems, Manila, Philippines, A1-1 to A1-15.
- Fok, Y.-S. 1992. Rooftops: The under-utilized resources. Proc. 1992 Reg. Conf. of International Rainwater Catchment Systems Association, Kyoto, Japan, vol. 1, 164-174.
- Fok, Y.-S. 1993. Importance of national policy for rainwater catchment systems development. 6th Int. Conf. on Rainwater Catchment Systems, Nairobi, Kenya, 27-31.
- Fok, Y.-S. 1982. Foreword in Proc. Int. Conf. on Rain Water Cistern Systems. Water Resources Research Center, University of Hawaii at Manoa, Honolulu.
- Fok, Y.-S., and Leung, P.S. 1982. Cost analysis of rain water cistern systems. Proc. Int. Conf. on Rain Water Cistern Systems, 210-219. Water Resources Research Center, University of Hawaii at Manoa, Honolulu.
- Sethaputra, S. 1986. Lessons from Thailand Jar Program. Paper presented at 3rd Int. Conf. on Rain Water Cistern Systems, Khon Kaen University, Thailand, 5 pp.
- Wirojanagud, P., and Chindaprasit, P. 1987. Strategies to provide drinking water in rural areas of Thailand. 3rd Int. Conf. on Rain Water Cistern Systems, Khon Kaen University, Thailand, B5-1 to B5-11.
- Tokyo International Rainwater Utilization Conference (Proceedings). 1994. Published by the Committee of the Conference, 633 pp. Sumida City, Tokyo, Japan (c/o Sumida City office, 1-23-20 Azumabashi, Sumida City, Tokyo, 130 JAPAN).

RAINWATER RESOURCES AND RAINWATER CATCHMENT SYSTEMS CONTEXT

Liu Changming, *Institute of Geography, CAS, Beijing 100101, CHINA*

Mou Haisheng, *Department of Urban & Environmental Sciences, Peking University, Beijing 100871, CHINA*

Abstract: The authors of the paper hold that a better understanding of rainwater resources and rainwater cistern systems will be further facilitating prosperity and developing context of rainwater cistern systems. The paper, approached from the view point of rainwater and rainwater process, raises a general conception system of water resources based on rainwater resources, reveals the role of rainwater on control of total amount of regional water resources, expounds relationship of mutual transformation and derivation among water resources of differing forms, and provides theoretical basis for scientific, rational and new water resources evaluation and sustainable development. It attempts to give a broader definition on rainwater utilization, based upon which to turn rainwater cistern utilization into an independent branch in water science.

Rainwater utilization, the earliest way in water resources utilization, has had a long history of several thousand years. In the first half of the 20th century, with drastic development of water-supply process followed the application of mechanical and power-driven techniques in river water and groundwater exploitation, interest in rainwater utilization has been declined. However, in the past twenty-odd years, rainwater utilization began to get rejuvenated and developed rapidly throughout the world with the occurrence of a series of issues on resources, energy, environment and population. Although rainwater utilization technique witnessed great progress, no perfect theoretical study on this respect has been yet obtained.

I. Connotation of Rainwater Resources

1.1 Rainwater -- A commonly seen precipitation in warm season

Precipitation consists of liquid and solid water in various forms from the atmosphere that fall to the surface of the earth. The transfer of moisture in the atmosphere to the earth surface in three ways of vertical, horizontal and condensation forms, which are commonly referred to as vertical precipitation, horizontal precipitation, and condensation water of the earth surface accordingly. In high latitude region, snow water occupies a great proportion of precipitation, whereas in

many arid and extremely arid areas, condensation water is of great ecological significance as well. Presently, as rainwater collection and utilization occupy a predominant position, the terms of "rainwater, rainwater resources, and rainwater utilization" are preferred.

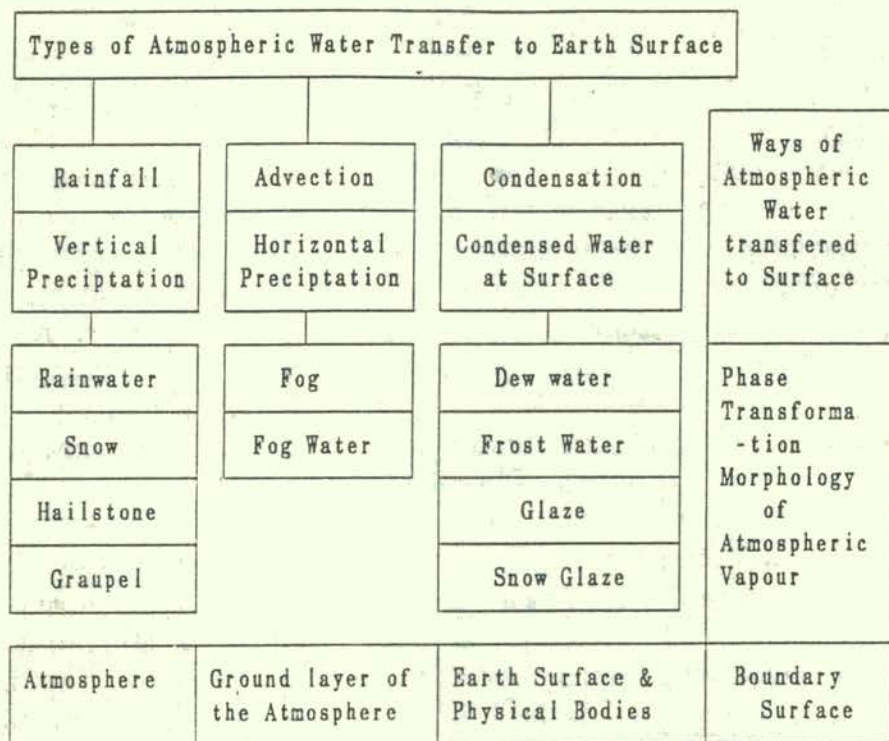


Figure 1: Ways of atmospheric vapor transfer to earth surface and morphology of atmospheric vapor

1.2 Rainwater resources

So far theoretical studies on rainwater utilization in various countries are all at a development stage and no harmonious concept has been raised to describe rainwater resources. Terms used in relevant literatures include: Rainwater Cistern System, Rainwater Catchment System, Rainwater Collection, Rainwater Harvesting System, Rainwater Storage, Runoff Farming, Rainwater Resources, Rainwater Use, Rainfed Agriculture, Rain-fed Crop, Rainwater Utilization, etc. They are all adopted by pertinent countries adaptable to their respective characteristics in the process of rainwater exploitation and utilization. They objectively reflect rainwater utilization conditions of these countries. For instance, rainwater cistern system or rainwater

catchment system are used in United States because one of the major subjects in rainwater utilization is to enlarge collecting area and build high-efficiency rainwater-collecting project in Hawaiian Islands where rainwater has been quite commonly utilized due to shortage of freshwater. In Thailand where rainfall is sufficient, the focus of attention is how to effectively store rainwater because of great seasonal variation in rainfall. Rainwater resourcefulization is extensively referred to in Japan because rainwater has not only been used in agricultural production and for domestic purposes but has been comprehensively exploited and utilized in tree planting in cities, flood control and hygiene. The term of rainwater utilization adopted by department concerned in China also properly reflects the knowledge of Chinese hydrogeographers in rainwater resources because the major channel in dealing with water shortage issue in arid and semiarid areas is water transfer and rainwater utilization is only a supplementary means.

In the paper all the processes relevant to direct use of rainwater as water source are defined as "rainwater resourcefulization" and indirect rainwater use as well as other forms of atmospheric vapor practices as broad-sensed rainwater resourcefulization. All the terms adopted in the process of rainwater resourcefulization such as flow concentration, flow collection and storage system are referred to as "rainwater cistern system", and water collected via rainwater cistern system is defined as specific (narrow-sensed) "rainwater resources". Broad-sensed rainwater resources are composed of precipitation resources, other forms of the atmospheric moisture and rain-induced energy resources. Rainwater resourcefulization involves in two channels, one is natural resource transformation process and the other, artificial transformation process.

Therefore, connotations of rainwater resources concept include 1) focusing on utilization of atmospheric vapor; 2) emphasizing on transformation process of and relations between rainwater and other forms of water resources; 3) direct usable rainwater; 4) artificial-induced rainwater transformation into available resources; and 5) water vapor resources exploitation (weather modification) as a direction for further development of rainwater resources.

1.3 Characteristics of rainwater resources

Rainwater resources are inexhaustible and immutable in nature whereas rainwater derivated surface water and groundwater resources are characteristic of reusable and renewable.

R a i n	Natural resources transformation process:
	1. Gravitational water recharge on the earth surface; 2. Rainfed agriculture, Rainfed/irrigation mixed agriculture; 3. Eco-environmental water use
U t i l i z a t i o n	Artificial resources transformation process:
	1. High-efficiency rainfed agriculture (slope-land flow collection, optimization of cropping system); 2. Groundwater recharge (channel, canal, deep-well replenishment); 3. Forest for artificial conservation of headwaters (grass, forest); 4. Water storage via reservoirs, lakes, and ponds (water retaining, water storage, water percolation); 5. Direct rainwater interception (flow collection from roofs, site, road); 6. Weather modification

Figure 2 Major channels for rainwater resourcefulization

1) The quantity of rainwater resources is the integration of relative finiteness (within certain temporal-spatial scope) with absolute indefiniteness (circulation), and the integration of definite quantity of supply with indefinite utilization value.

2) Quality relativity: No special specifications on quality grading of natural rainwater existed which is rather done according to demand and objectives of utilization of human society.

3) Sociology of rainwater resources: Rainwater and its derivated resources are linked with social, economic and technical levels of a certain temporal-spatial scope. Because of their sociology, changes in their quality and quantity may take place or will be redistributed both in region and in time.

4) Duality of gains and losses of rainwater resources: This is referred to the features of standard of human social values, the excessive rain will cause flood and waterlogging disasters while deficient rain will lead to drought.

5) Unevenness in temporal-spatial distribution of rainwater resources: The randomness of rainwater distribution leads to the temporal-spatial regulation in distribution of rainwater resources, i.e., water storage by means of collecting and water transfer. It is possible to regulate and redistribute rainwater resources, but the total amount remains basically unchanged within certain temporal-spatial scope.

1.4 Theoretical framework of rainwater use and assessment of rainwater resource

Theoretical system and research contents of rainwater cistern system (rainwater utilization), a subject in the process of gradual establishment and development, are listed in the following tables.

Table 1: Connotation/theory of rainwater resources, research methods & contents

1. Theoretical research contents of Rainwater resources	2. Research method of rainwater Resources
Concept, connotation, definition	Ways of exploitation and utilization
Concept system of rainwater resources	Modification of rainwater utilization
Rainwater environmental process	Simulation of rainwater process
Moisture transformation model	Rainwater assessment method
Theory of quantity modification	Assessment method of various types
Dynamic structure of rainwater resources	Prediction method of rainwater process

Table 2: Major research contents of rainwater collection (RC)

Elements of RC	Influential Factors	Corresponding Theoretical Issue	Corresponding Technical Issue
I Catchment surface	Precipitation amount (PA)	Determination of guaranteed rate of PA	Design of collecting surface
II Storage Device	Storage space	Determination of collection efficiency	Construction technique of collecting surface
III Purification Device	Environmental Quality	Calculation of collecting surface	Manufacturing technique of storage device
IV Water intake device	Energy dynamics	Calculation of device Capacity	Manufacturing of control facilities
V Protection facilities	Economic ability	Material Selection & Economic Analysis	Manufacturing of water-Intake device
VI Maintenance of facility	Management level	Utilization and Management/maintenance	Layout of Collection system

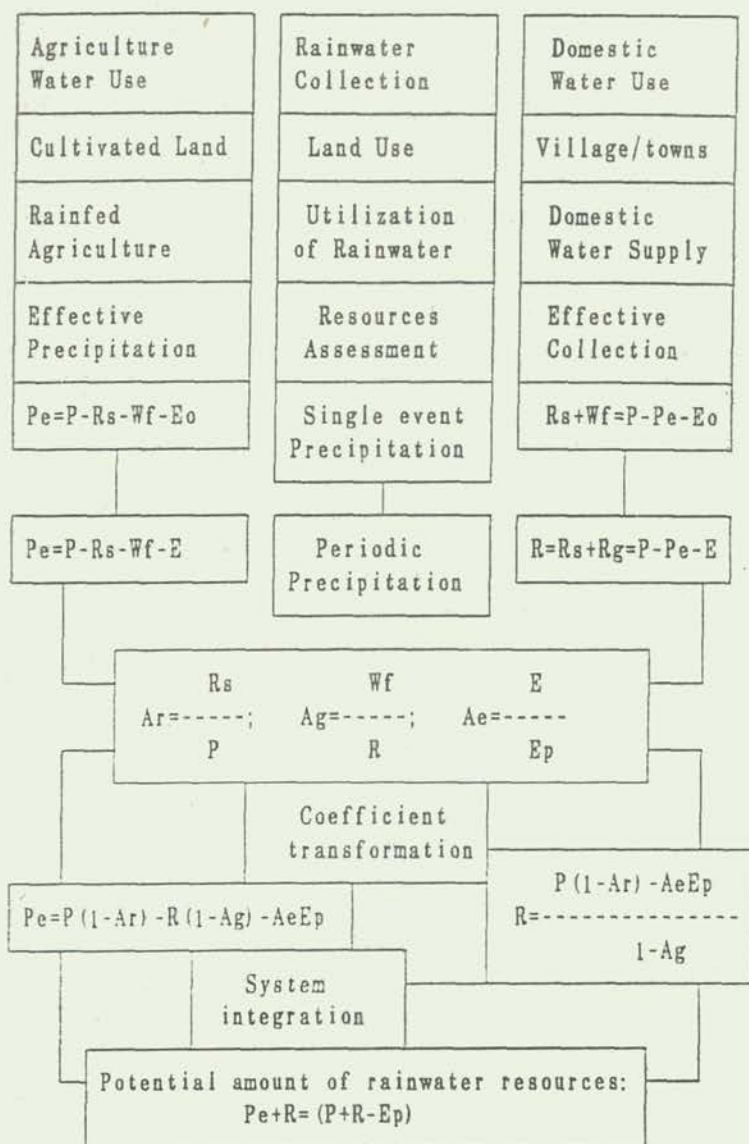


Figure 3: The system for rainwater resources assessment

In above figure, P--precipitation; Pe--effective amount; Rs and Rg--surface runoff and subsurface runoff; $R = Rs + Rg$; Wf--seepage or groundwater recharge; E, Eo and Ep denote respectively evapotranspiration, evaporation of rainy period and groundwater evaporation.

The left blocks in Figure 3 indicate direct utilization of rainwater resources.

As for effective precipitation (P_e) for crop water utilization, it is clear that surface runoff (R_s), rainy period evaporation (including the amount intercepted in crop branch and leaves), and rainwater replenishment (W_f) input to groundwater layer via deep seepage are excluded. Only the amount of precipitation that can be absorbed by crop root system at root layer via seepage can be directly utilized by crops. But as for R_s and W_f , they can still be utilized. The lower part of Figure 3 gives three rainwater transformation coefficients of $a_r = R_s/P$, $a_g = W_f/R$, and $a_e = E/P_e$ which respectively represent quantitative relations of rainwater resources transformation among surface water, groundwater and water returning to the atmosphere. This provides an indication of the extent of rainwater that can be controlled.

2. Total Control of Rainwater Resources and Derivation Characteristics

Narrow-sensed rainwater utilization concept mainly refers to rainwater collection for domestic utilization and rainfed agricultural utilization, termed rainwater "direct utilization" or primary utilization. In addition to rainwater direct utilization, water resources in rivers, lakes, reservoirs and groundwater collected from runoff producing precipitation, or precipitation collected from natural catchment system are called rainwater "derivated resources", a portion of broad-sensed rainwater resources. Exploitation and utilization of derivated rainwater resources is referred to as "rainwater reutilization". Rainwater resources can be derivated and used many times, this can be regarded hydrologically as rainwater reutilization. Furthermore, rainwater utilization implies extensively (as shown in Figure 4), included not only domestic rainwater utilization and rainwater utilization for agricultural purposes but also various aspects concerning rainwater resources utilization such as soil and water conservation, water source conservation, urban flood control and eco-environmental improvement.

Rainfall -- Rainwater Resource						
Leaching	Interception	Collection	Percolation	Runoff	Seepage	Evapo-transpiration
Atmosphere	Plants	Projects	Soil Reservoir	Surface Reservoir	Underground Reservoir	Air Reservoir
Air Purification	Vegetation Moistening	Drinking Water Sup.	Agricultural Production	Urban, Ind. & Agr. Use	Groundwater Recharge	Crops Growth
Primary Use		Second Use & Storage		Tertiary Use		Mixed Use

Figure 4: Model for broad-sensed rainwater resources transformation process

The combination of water vapor transfer of a region with effect of underlying surface forms precipitation system, which generates natural precipitation, the total source of water in various forms on Earth (excluding deep geological water). Precipitation plays the role of general modifying the quantity of water resources. In the light of the extension of the concept of rainwater resources, the structure of regional rainwater sources is divided below.

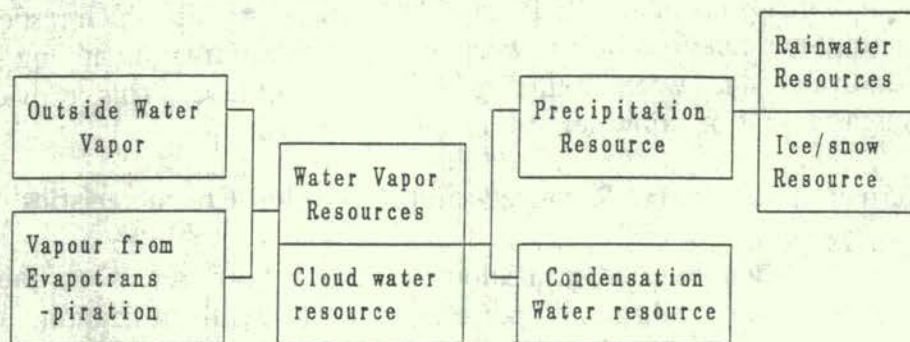


Figure 5 Structural division of regional rainwater resources

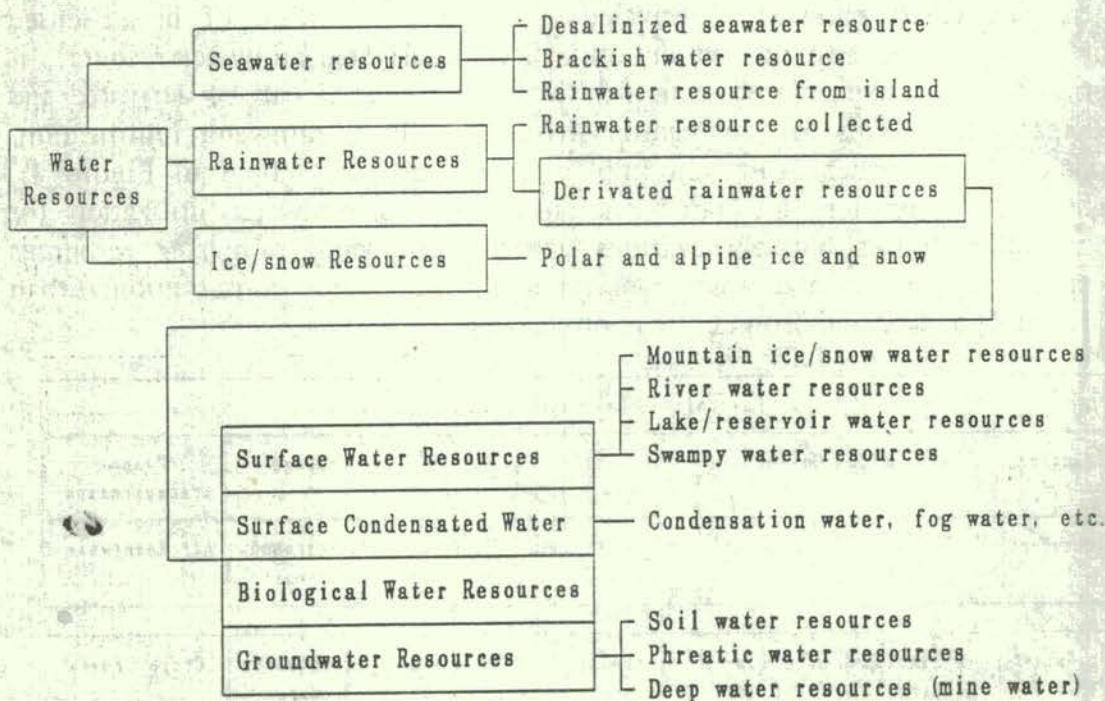


Figure 6: Spectral analysis of rainwater-based regional water resources

From the above figure one can see that rainwater resource is the third principal form of water resources on Earth, only next to seawater resources and polar ice/snow water resources. For land, rainwater resource constitutes the principal form and source of water resources. Surface water and groundwater on Earth are mainly rain-generated with the exception of that partially from snow-melt water and deep magmatic water, this is regarded as broad-sensed rainwater resource concept. The general meaning of rainwater resource refers to the total amount of available stored water, plant intercepted flow, moist water, and rainwater stored with community project, commonly known as collected and stored rainwater resources.

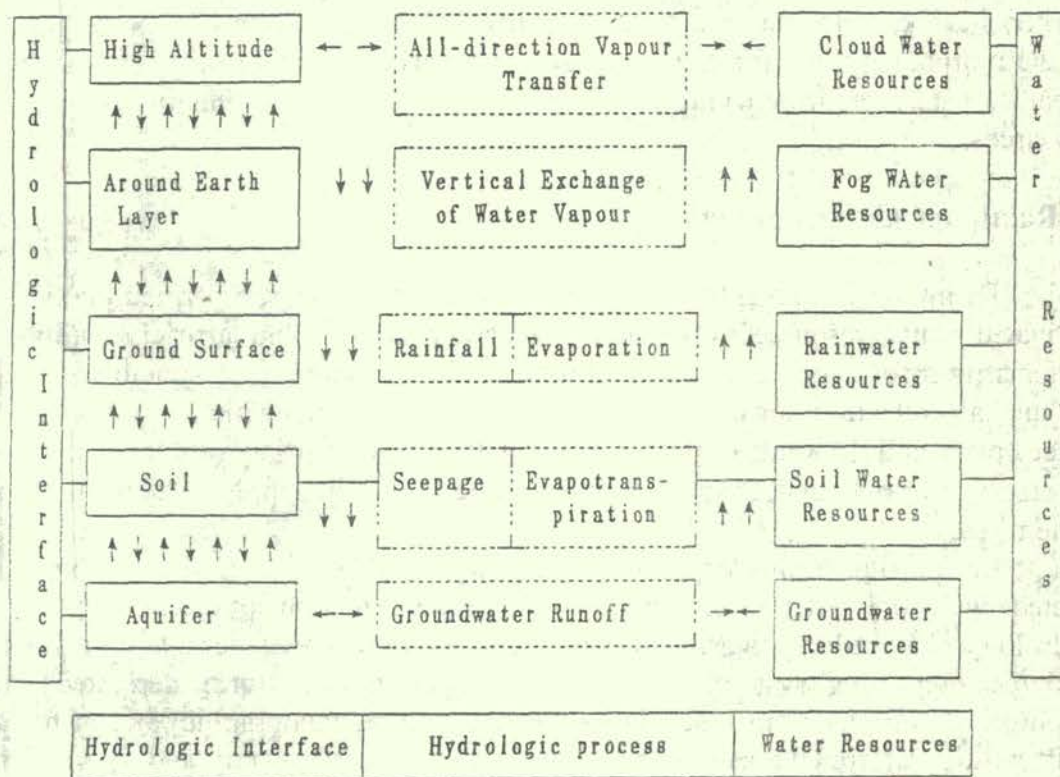


Figure 7: Associated diagram of hydrologic interface, hydrologic process and water resources

Water resource is a product of rainwater process, and classification of water resources should be based on rainwater process and hydrologic interface (Figure 7). With regard to water storage and migration process in the rainwater transformation and derivation movement on Earth, atmospheric-hydrologic process, pedologic-

-hydrologic process, and surface-water hydrologic process are involved. Physical basis that supports these hydrologic processes is hydrologic interface which is divided into gas-solid interface, gas-liquid interface, and liquid-solid interface. Different hydrologic processes take place in different hydrologic media, i.e., gaseous hydrologic medium, liquid hydrologic medium, and solid hydrologic medium. Water, exists in different median the forms of various derivated rainwater that can be exploited and utilized by man or offer direct service for man, falls into the category of water resources. Various rainwater-derivated resources coexist, and different concepts are used for them according to different fields of application. In the light of the morphology and forms of storage, gas-bearing water, earth-contained water, organic water, environmental water and society water are identified for water resources.

3. Rainwater Cistern System

Rainwater is a potential water resource which can be transformed into various derivated water resources with other necessary natural and artificial supporting systems (transformation and storage system). Natural supporting system consists of air media, collection surface river bed, lake basin, soil media, geologic storage space, plant body, swamps, glaciers, etc. Artificial supporting system is composed of reservoir, pond and dam, catchment system, water supply system, farmland system, etc.

In drainage basins or areal scope, water bodies of different morphologies related with precipitation or precipitation transformation process in terms of hydrology, hydraulic power, and water conservancy are generally called water resource supporting system; systems that store and transform derivated water resources of various forms such as geologic structure, topographic landforms, and artifacts are referred to as water resources supporting system; and systems that acquire, transfer, treat and discharge water artificially are termed water resources utilization system.

According to connotations of rainwater resources, water resources should first of all possess generation system (precipitation system), transformation system, storage system, and retransformation system (including utilization system). In the four principal water resources systems, artificial influence and involvement is necessary because the influence and involvement of the kind is taken exactly as water utilization activities. Factors of artificial influence will be increased with population growth and economic and technical development.

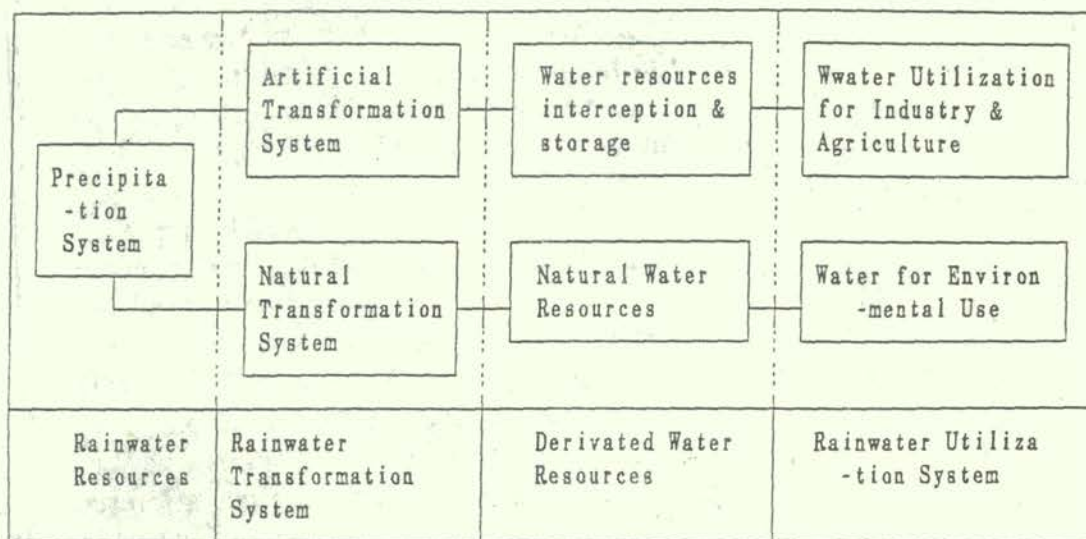


Figure 8: Associated diagram of rainwater with various forms of water resources

Rainwater resources are intermittently distributed both in time and space as well as in great fluctuation whereas derivated water resources are relatively stable and can be involved in continuous water supply activities. The first step of rainwater utilization is to turn temporally and spatially in continuous and instable rainwater resources into various derivated water resources with constant water supply capabilities.

From Figure 8, one can find that a very important water resources transformation process exists from potential rainwater resources to various kinds of derivated water resources readily to be utilized. Without this kind of modification process, most of the consequences caused by rainfall fluctuation would be alternations of two disasters of drought and waterlogging. It is right because of varying natural processes and artificial measures that exercise rainwater modification in time and space that the rainfall process becomes evenness without generating apparent impacts on human society and natural environment. Water resources transformation system consists of two major components of natural and artificial. The artificial component is becoming greater, the rapid development of global reservoirs and various water utilization techniques offers a good demonstration.

Natural rainwater transformation system contains rivers, lakes, swamps, vegetation, soil and subsurface deposition which used to be a benign natural circulation system. However, because of blindness in human activities such as

deforestation, groundwater overdraft and reclamation, the rainwater transformation system was damaged which led to frequent occurrence of natural disasters of water and soil loss, depletion of water source, and drought and waterlogging.

Both the quality and quantity of water resources that human society can be utilized depends upon water transformation system exists between natural precipitation system and various forms of water resources. The representation of predominant position of artificial transformation subsystem in rainwater transformation system is in two aspects: one is the newly built pure artificial rainwater transformation system such as reservoirs, cisterns, and collecting surface and the other, natural water transformation system improved and controlled by man such as construction of air reservoirs, soil reservoirs, underground reservoir, forest effect, and modification system. They correspond to countermeasures and projects of weather modification, land amelioration, groundwater recharge, afforestation and interbasin water transfer. It can be inferred that prospect of water resources utilization is inevitably bound up with control of various links in water transformation system step by step.

The fact that water treatment and water discharge is also an important component in water resources utilization system in the process of water resources utilization structure analysis and water resources exploitation planning has long been neglected. Consequently, a series of problems on water pollution were resulted. Therefore, in the structure of rainwater resources system illustrated in Figure 8, water treatment and waste water resources transformation system should be added for the purpose of purifying waste water discharged from industry, agriculture and cities, making the purified water entered into environmental water body to take part in the next water circulation process.

4. Conclusion

The exploration of the concept of rainwater resources reveals the origin of water resources, enriches conception system of water resources in types and scope, and expands water resources research from land to the atmosphere, soil and social environment. The description of the relationship derivated between total control of rainwater and water resources of various forms reveals the characteristics and sociology of dynamic changes of water resources. The discussion of generation, transformation, derivation, storage and utilization of rainwater resources from systematic point of view leads to us a better understanding of the essence of water resources system.

The substantiation of concept of rainwater resources and elaboration of the connotation concerns the broader prospect of their application which again is based upon practice. Research on natural rainwater and applied research on the adaptation of rainwater to human society will bound to promote the development of rainwater cistern system towards a subject discipline with specific research objectives and purposes. In terms of introduction of modern science and technology, an important development orientation is to perfect the theory of rainwater cistern system with mathematic and physical methods, and to develop hardware system on rainwater utilization by using high-technology.

References:

- [1] Liu Changming, Mou Haisheng, 1993. Rainwater Catchment System in Agricultural Area of Northern China. Agro-ecosystem.
- [2] Liu Changming, Wei Zhongyi, 1991. Agrohydrologic-water Resources in North China. Science Press.
- [3] Mou Haisheng, 1994. Rainwater Resourcefulization: Theory and Methodology, Ph.D Thesis of the Institute of Geography, CAS.
- [4] Mou Haisheng, Liu Changming, 1993. Method for Rainwater Resources Assessment. Resources Exploitation and Conservation, 9(3).
- [5] J. E. Gould, 1991. The Contribution of Rainwater Catchment Systems to the International Drinking Water Supply and Sanitation Decade: Lessons from Thailand. Proceedings of the 5th International Conference on Rainwater Cistern Systems, Keelung, Taiwan.
- [6] Yu-Si Fok, 1991. Progress of International Conference on Rainwater Cistern System. Proceedings of the 5th International Conference on Rainwater Cistern Systems, Keelung, Taiwan.

Rainwater Catchment and Utilization in Gansu, China

Zhu Qiang¹

Wu Fuxue²

Abstract

A systematic investigation on the rainwater system to solve the serious problem of drinking water supply for the farmers and their livestock and to develop small size irrigation has been carried out in Gansu province, China since 1988. 33 testing plots lined with various material were set up and the relationship between the rainfall collection efficiency (RCE) and the amount and intensity of the rain and the initial moisture content of the material of the collection field were determined. Based on the rain records of 9 typical gauges, the yearly RCE of the regions with different annual precipitation in the years with hydrologic frequency of 50%, 75% and 95% were worked out. The rainwater catchment system including 80-120 m² of collection field composed of cement tile roofs and concrete pavement courtyard were designed and built. To the end of 1994, the drinking problem for 27,860 families, 141,600 populations and 43,000 large livestock have been successfully solved by using this technique. More than 20 rainwater catchment-irrigated pilots have been established and good economic results were obtained. Now, a program to collect the rainwater to supply 100,000 to 150,000 families' drinking water each year and to develop the small size irrigated orchards and cash crop lands are in successful progress.

Introduction

The arid and semi-arid area of Gansu province, China, located at the middle and east part of the province, is composed of loess plateau and hilly land crisscrossed with gullies and ravines. Both the surface and ground water are few in this area. Owing to the frequent draught, the agricultural production level is very low and the people in the rural area lead a poor life. Particularly, about 1.5 million people with their livestock have difficulty to get enough drinking water. The government has to bring water from a far distance for them with a cost of 5-6 million yuans each year. So, this area is considered as the most dry and poorest district in the province as well as in the whole nation. To raise the people's living standard and promote the social and economic development of the areas, the key measure is to solve the water problem. The only potential water resources is the rainwater. The inhabitants have a long tradition of storing the rainwater collected from the roof, courtyard, road and slope for drinking and daily use during dry seasons. But since most of the farmers' house roofs are made of straws mud and other rainwater collecting places are natural soil, the water collecting efficiency (RCE) is very low. Almost no runoff can be produced during the small rainfalls which represent most part of the yearly precipitation. So, it is necessary to adopt the anti-seepage treatment for the rainwater catchment as well as the storage tanks in order to retain sufficient water for daily use and irrigation so that the yield of the land can be raised and the farmers' life can be improved.

In the recent years, rainwater catchment techniques have made a rapid development around the world (Waller, D.H., 1989). In Canada, Bermuda, North Africa and Thailand, the measure has been widely adopted to solve the drinking water problem. Research on the rainfall-runoff model has been presented in some literature. However, there are few investigations so far on the field and laboratory RCE tests, especially RCE on the lined surface. It is also imperative to carry out a special study on the technical and economic feasibility of the adoption of rainwater cistern system in the middle and east part of Gansu where only 250-450 mm yearly precipitation is available. With the support of the

¹ Chief engineer, Gansu Provincial Research Institute of Water Conservancy, 76 Gao'an Road, Lanzhou, 730000, P.R.China.

² Senior engineer, Gansu Provincial Research Institute of Water Conservancy, 76 Gao'an Road, Lanzhou, 730000, P.R.China.

Provincial Government and the Provincial Bureau of Water Resources, a large-scale experiments and extension work were carried out since 1988 and satisfactory results were obtained.

Experiments and the Results

To study the RCE from surfaces composed of various material under different rain condition, 5 natural rain-runoff testing stations, including Cuijiahe of Tongwei County, Yuezhong, Daguo and Fanpo of Huining County and Yantongguo of Jinyuan County, were set up. In these stations, 22 testing sections with area of 50-150 m² each lined with concrete slabs, cement tiles, clay tiles (machine made or hand made), plastic films or covered with compacted lime-soil or loess were established. A section with natural soil surface was also set up for reference. To accelerate the experiments, a testing station in Shifeng with 5 sections of 20 m² each using artificial sprinkling to simulate the natural rain was built in 1989. Besides, testing on 6 sections of 15 m² each also went on in the runoff laboratory of the Shaanxi Mechanical Institute. The slopes of the above testing sections are 1/9, 1/10 and 1/50, except the section lined with roofing material where the slope was 1/3.5.

During each simulated rain test, the pluvial amount and the intensity is determined according to the real local situation, where the amount and intensity of most rainfalls in a year is less than 10 mm and 0.04 mm/min, respectively. Only 2.9% and 1.9% of the yearly rainfalls have an amount greater than 40 mm and intensity 0.3 mm/min. So, in the analogous tests, the amount ranges between 5 and 40 mm and intensity between 0.02 mm/min and 0.3 mm/min.

In the natural rain tests, auto-recorded rain gauge was used to register the total rainfall and the rain history curve, while in the simulated tests, the can test method with a can interval of 0.25 m was used for the measurement of the rain amount, then the intensity was calculated with the raining time. Volumetric method was used to measure the runoff in both natural and analogous rain tests. Besides, the compacted loess, lime and cement soil were sampled and tested for their moisture before rain.

In the four year experiments, there were in total 311 natural rain tests and 455 analogous ones. Based on these data, the least square method was used to work out the correlation equations between RCE and the rainfall characteristics (rainfall amount and intensity) and the initial moisture. The slope is not included in the model, because the data were not enough. We will have a qualitative discussion in later paragraphs. The pattern of the equation can be selected according to the principle of maximizing the correlation coefficient and the following types are adopted.

$$RCE = 1 - c \cdot P^{-a} \cdot I^{-b} \cdot W^{-d} \quad (1)$$

$$RCE = 1 - c \cdot P^{-a} \cdot e^{-bI} \cdot W^{-d} \quad (2)$$

$$RCE = 1 - c \cdot P^{-a} \cdot I^{-b} \cdot e^{-dW} \quad (3)$$

where P is the rainfall amount, I is the intensity, W is the initial moisture, a, b, c, d are constants. For the concrete and cement tile sections, the effect of the initial moisture is not significant, only the rain characteristics were taken into account in the RCE equations. The adopted equation can be selected from equation (9)-(12) in the light of the same principle mentioned above.

$$RCE = 1 - c \cdot P^{-a} \cdot I^{-b} \quad (4)$$

$$RCE = 1 - c \cdot e^{-aP} \cdot I^{-b} \quad (5)$$

$$RCE = 1 - c \cdot P^{-a} \cdot e^{-bI} \quad (6)$$

The experiment results of various sections are shown in table 1 and 2. The correlation curves are illustrated in figure 1-8.

Table 1 The RCE equations from the natural rain tests

Name of station	Material	Number of data	No. of equation	a	b	c	Correlation coefficient R	F-test number	F _{0.01}
Cuijiahe of Tongwei	Concrete	49	(4)	.0739	.467	.0711	.672	12.4	5.09
	Plastic film	35	(4)	.136	.335	.242	.598	5.75	5.29
	Lime-soil	27	(6)	.103	3.0	1.26	.93	49.1	5.49
	Loess	27	(4)	.1	.186	.528	.77	11.2	5.49
	Natural soil	32	(6)	.0993	1.33	1.19	.66	7.2	5.35
Yue-zhong	Concrete	34	(4)	.361	.257	.365	.894	39.8	5.31
	Cement tile	43	(4)	.424	.261	.208	.748	16.5	5.15
	Clay tile [*]	32	(5)	.0485	.127	.551	.751	12.1	5.35

* machine made

Table 2 The RCE equations from the simulated rain tests

Name of station	Material	Number of data	Equation number	a	b	c	d	R ^{**}	F-test number	F _{0.01}
Shifeng	Concrete	48	(6)	.12	2.82	.314		.562	6.77	5.1
	Plastic film	42	(6)	.508	.668	1.65		.883	44.8	5.16
	Lime-soil	21	(6)	.235	3.79	1.68		.796	9.8	5.78
	Loess	19	(6)	.179	2.38	1.14		.856	13.7	5.93
	Clay tile [*]	52	(4)	.309	1.43	.7		.58	8.11	5.06
Shaanxi Institute Lab.	Loess i=.05	75	(3)	.408	.32	3.95	9.55	.846	44.1	4.08
	Loess i=.02	32	(2)	.244	1.79	.028	2.2	.979	155.7	4.57
	Cement soil	70	(1)	.546	.099	.00023	5.03	.933	109.2	4.1
	Concrete i=.02	42	(4)	.336	.071	.123		.672	10.4	5.19
	Concrete i=.1	45	(6)	.569	3.0	.585		.868	41.8	5.15

*hand made

**correlation coefficient

[†] denotes slope

We can have the following conclusions from these results.

1. The F-tests of all equations indicate that the correlation is significant. The significance level is greater than 0.99. So, all these equations are reliable.
2. RCE is positively correlated to the amount and intensity of the rainfall as well as the initial moisture of the material.
3. At a certain value of the rainfall amount, RCE equals to zero. That is to say, the rain entirely infiltrates into the material. The initial infiltration, we call hereby the zero RCE rainfall amount, increases with the decrease of the intensity. For concrete slab and cement tiles, the initial infiltration is very small. Runoff can occur even in a small rain.

Analysis of the results

1. The analysis of the yearly RCE.

In order to study the feasibility of the rainwater harvesting and storage techniques and provide base for scientific determining of the scale of the rainwater cistern system, an analysis of the yearly RCE of various lined catchment in the year of different hydrological frequency is necessary. Since in a dryer area and dryer year, there are more small rainfalls in the whole year. So, different areas and different years may have different yearly RCE. Nine hydrological stations with more than 20 years of measuring data were selected from 60 stations distributed over an area of 80,000 km². The nine represent 3 categories of annual precipitation of 400-500 mm, 300-400 mm, and 200-300 mm. The rainfall history curves of 3 typical years representing the frequency of 50% 75% and 95%, respectively of each of the 9 stations are picked out from the data. The runoff of each rainfall from various kinds of catchment can be calculated using the results of RCE equations listed in table 1 and table 2. With the yearly sum of the runoff water, the yearly RCE of all the 3 typical years of the 9 stations can be obtained. In the calculation of the runoff, only the rain is taken into consideration. The runoff from the snow is negligible because snow in this area occupies only a small portion of the precipitation and what is more, most of it is usually blown away by the strong wind or evaporated.

The yearly RCE can be calculated by the following equation:

$$E_y = \frac{\sum_{i=1}^n P_i E_i}{\sum_{i=1}^n P_i} \quad (7)$$

where E_y is the yearly RCE, P_i is the amount of each rainfall, E_i is the RCE of each rainfall, n is the number of rains in a certain year. The calculated results are listed in table 3.

The following points are drawn from the results.

(1) The yearly RCE varies with the location and year. We can see that the less the annual precipitation and dryer the hydrological year, the less the yearly RCE. That is because in a dryer area and a dryer year, the rains in a year are mostly small ones with less rainfall amount and intensity. Furthermore, we can see that the harder the surface of catchment, such as that of concrete slabs and cement tiles, the smaller the difference of the yearly RCE between different areas and different years. That is to say, concrete slabs and cement tiles have a more stable yearly RCE. So, it is all the necessary to adopt the high anti-seepage performance material in the dryer area to get a stable water supply.

(2) The yearly RCE also varies with the surface material. The concrete and cement tile catchment have the highest efficiency. The yearly RCE can reach 60-80%, in some sections, can even be greater than 90%. According to their efficiencies, the material can be arranged in the follow orders: cement tile, concrete slabs, cement soil, clay tile (machine made), buried plastic film, clay tile (hand made), compacted loess and lime soil. For a same material, the yearly RCE may be different owing to the quality of the material and the construction of the sections.

(3) The effect of the catchment slope on the RCE. We can conclude that the steeper the slope, the larger the RCE. RCE of a concrete section with slope of 1/50 is 23-27% less than that of the section with slope of 1/9. Besides, the effect of the catchment slope is more evident on the yearly RCE of the surface lined with soil. So, it is better to adopt a steeper catchment, however, owing to the space limit, it is recommended that the slope of the courtyard should be around 1/10 and the roof 1/3.5.

2. Economic analysis

Table 3 The yearly RCE of the various lined catchment in the years of different frequency

Annual precipitation	Frequency (%)	Concrete				Cement tile	Plastic film	Lime soil	Compacted loess				Clay tile1	Clay tile2	Cement soil
		1	2	3	4				1	3	5	6			
400	50	63.7	55.5	78.4	86.7	75.3	42.7	16.6	19.6	30.9	27.2	20.3	50.2	40.5	53.0
/	75	62.9	53.2	77.6	85.9	74.0	40.5	13.8	17.3	28.5	25.0	17.4	48.0	38.2	50.8
500	95	57.6	45.4	76.7	83.4	69.0	32.4	10.5	13.2	24.3	19.4	10.0	38.8	30.7	41.5
300	50	64.1	54.7	78.6	86.4	74.5	42.5	17.9	19.8	31.5	27.8	20.2	48.9	40.0	52.2
/	75	59.4	48.9	77.4	85.0	71.6	36.2	12.4	14.3	27.2	22.6	12.4	42.0	33.9	46.3
400	95	55.5	43.5	76.0	82.6	66.8	31.1	8.2	11.7	22.3	17.7	9.5	37.2	29.2	39.9
200	50	57.0	48.2	76.9	85.0	70.9	36.1	10.3	13.8	25.8	21.8	11.5	41.2	33.9	46.9
/	75	53.9	42.2	76.0	82.4	65.8	30.3	8.1	10.9	22.1	17.3	8.3	34.2	33.9	39.5
300	95	52.0	37.0	74.8	79.8	61.6	25.5	5.1	8.8	18.1	13.7	3.6	30.1	23.6	33.0

Note: 1, The bold numbers in the table denote: 1- Cuijiaba station of Tongwei County; 2- Yuezhong County station; 3- Shifeng simulated rain station; 4- Concrete section of the Shaanxi Mechanical Institute Laboratory (SMIL); 5- Loess section with slope of 1/50 in the SMIL; 6- Loess section with slope of 1/10 in the SMIL.
2, Clay tile1 is machine made, clay tile2 is hand made.

Table 4 The comparison of yearly expense per unit of collected rainwater of various lined catchment (yuans/m³)

Frequency of year	Concrete slab	Concrete		Clay tile1	Clay tile2	Cement soil	Buried plastic film	Compacted loess		Lime soil
		1	2					1	2	
50%	1.82	1.5	1.81	2.27	2.81	2.85	1.66	1.66	1.66	17.7
75%	2.23	1.86	2.56	3.18	3.78	3.82	2.4	2.4	2.4	31.4
95%	3.02	2.6	3.79	4.83	5.7	6.02	3.9	3.9	3.9	60.6
Average	2.36	1.99	2.73	3.43	4.1	4.23	2.65	2.65	2.65	36.6

Note: Clay tile1 and clay tile2 see the footnote of table 3

(1) The optimal selection of the catchment material. In order to have an economic analysis of the rainwater cistern system, it is necessary to compare various lining material from the view point of economy. The comparison is based on the yearly expense per unit of collected rainwater. The expense includes depreciation and operation cost. The yearly collected rainwater for years with various frequency can be calculated using the figures in table 3. The results of comparison are listed in table 4.

The economy order of various lining materials can be arranged as follows: cement tile, concrete, compacted loess, clay tile (machine made), clay tile (hand made), cement soil, buried plastic film, lime soil. It is reasonable to give priority to the cement tile and clay tile, because they can be used to improve farmers' houses at the same time to solve their drinking problem. If the rainwater collected from the roof is not sufficient, the concrete lined courtyard should be added.

(2) The economic feasibility of the rainwater cistern system for drinking purpose. The quota of water for daily use per capita is determined in the light of the real situation taking the standard set up by the Ministry of Water Resources as a reference. It can be seen in table 5.

Table 5 Quota of water for daily use per capita and per head of livestock (l/day)

	Normal year	Extremely dry year
Per person	10	6
Per head of livestock*	30	20

* not including the pigs and sheep

We should say that this is a very low standard but is a realistic standard for this area.

According to the circumstances of the farmers' house, it is planned first to fully use the roof already lined with clay tile as the rainwater catchment, when the runoff is not sufficient, then the concrete slab courtyard would be added. In most cases, the roof of the houses in this area is only covered with straw mud, then cement tile should be used as roofing to ensure a good water harvesting. In each case, the government will provide funds only for the materials to be purchased, such as cement steel, timber, etc. and subsidize part of the transportation fee of sand and gravel. The owner of the houses are responsible for the labor force for tiling and paving courtyard, etc. The fund provided by the government for a family with 5 persons in different cases is listed in table 6.

Table 6 Government fund for the rainwater cistern system of one family

Case	Yearly precipitation mm	Roof m ²	Courtyard m ²	Government fund in yuans			
				Roof	Courtyard	Tank	Total
Existing roof with clay tile and concrete slab courtyard	250	50	140		426	200	626
	350	50	84		258	200	458
	450	50	57		177	200	377
Existing roof with clay tile2 and concrete slab courtyard	250	50	135		414	200	614
	350	50	78		243	200	443
	450	50	52		162	200	362
Newly built cement tile roof and concrete slab courtyard	250	50	113	165	348	200	713
	350	50	59	165	186	200	551
	450	50	32	165	102	200	467

Note: Clay tile1 and clay tile2 see footnote of table 3

It can be seen from table 6 that the government fund per capita for the rainwater catchment system for the drinking water purpose ranges between 72 and 143 yuans, depending on the different cases and annual precipitation and its average is 102 yuans. No operation fee is to be provided by the government. According to the five year plan (1991-1995) of drinking water supply project in Gansu

rural area, the government fund per capita will reach 143 yuans. Statistics of 11 existing and under construction drinking water projects shows that the construction cost per capita ranges between 65 and 280 yuans, and the average is 147 yuans. Each year the government has to subsidize operation fees of 6 yuans per capita. So the rainwater catchment project is an economic alternation for solving the drinking problem in the rural area of this district.

(3) The economic feasibility of the rainwater cistern system for irrigation purpose. The cost of the rainwater cistern system to supply the irrigation will be relatively high, so the crops irrigated by this system should be cash crops only, such as fruits, vegetables, seedlings, etc. The high efficiency method such as drip techniques should be adopted to save the limited water. The experiment results of some irrigation stations in the nation are consulted to estimate that the water demand of orchards using the drip irrigation system is 280-335 mm. Let us take an annual precipitation of 450 mm and another with 350 mm as basis for the further analysis. The effective rainfall during the growing seasons is 250 and 200 mm respectively, the required irrigation is 73 and 116 mm. The necessary water collected area to supply one mu (Chinese land unit, equal to 0.0667 ha.) of orchard is 154 m² and 304 m². The ratio between water catchment and irrigated land is 0.23:1 and 0.45:1, respectively. It is roughly estimated that the storage coefficient (ratio between storage capacity and the yearly runoff) is 0.4. A tank of 20 m³ is needed to irrigate one mu of land in the former area and that of 30 m³ for the latter.

It is estimated that the government should provide 1280 and 1800 yuans respectively for the material to be purchased and transportation charge of sand and gravel for one mu of land irrigated by rainwater cistern system for the two areas. Adding the values of farmers' labor force to the above sum provided by the government, the total cost will arrive at 1930 and 2750 yuans, respectively. According to the investigation made in this area, the yields of the irrigated orchards will increase by 30-60% over the non-irrigated orchards. For the two areas, the net benefit of one mu of irrigated orchard will be 300 and 450 yuans and the time for recovering the total investment will be 7.4 and 6.9 years, respectively. The government fund for one mu of irrigated land is 1500 yuans in average. This is less than the price for one mu of irrigated land developed by some large-scaled irrigation project in Gansu province. The rainwater cistern irrigation system has also the advantage of very low operation cost as compare with the major irrigation projects. So, the rainwater catchment irrigation project is also economically feasible.

Extension

Together with the experiments, this techniques have been demonstrated and extended since 1990. By the end of 1994, 2.4 million m² of rainwater catchment mainly lined with cement tiles and concrete slabs had been built. About 22,280 water tanks whose wall are lined with cement mortar were also built. According to the measurement made in these cisterns, the yearly RCE reached 67-70%. In 1991, a serious draught seen only once in 40-50 years occurred. The farmer who owned a rainwater cistern system including 80-120 m² of rainwater lined catchment, a water tank with a capacity of 18-25 m³, had enough water for the family's daily use. While in the place where this system has not been built, people suffered seriously from the water problem. So this system is warmly received by the farmers. The governor and the provincial governmental departments also pay great attention to the extension. In 1992, the government made a decision to provide 4-6 million yuans each year to support this system to solve every year 10,000-15,000 families' drinking problem. It is planned to solve the drinking problem of 100,000 families with 500,000 family members, one third of the 1.5 million people who now have serious difficulty in their drinking water before the year of 2000.

Advancement has also been made on the irrigation development by adopting the rainwater catchment technique. 22 demonstration sites with a total irrigated land of 20 mu has been set up and

the yields are quite satisfactory. For instance, at Fanpo, Huining County, 2000 yuans of income were obtained in 1991 from 200 m² of land of seedling irrigated by the rainwater cistern system. In the mountainous area of Yuezhong County, 16 green houses were established in 1993 and produced the first vegetable products in this area. Now the government and people regard this as a way to help the farmers to get out of their poverty and to promote the social and economic development of this area.

Conclusions

1. Experiments indicate that the adoption of a lined water catchment to collect the rainfall can raise the yearly RCE to 60-80%. The measure can solve the drinking water supply for the arid and semi-arid mountainous areas with precipitation only 250-450 mm and has the advantages of simple technique, low cost and adaptability to the wide area.
2. The rainwater catchment can supply water to a small size irrigated land using high efficient irrigation method. The cost can be returned within 6-7 years. The government fund for the development of unit irrigated land is equal to or less than that of the major water projects. The operation cost can be afforded by the farmers. Furthermore, the major irrigation project is very difficult to convey the water to the whole hilly lands which are crisscrossed by many gullies and ravines, while the rainwater catchment enable the farmers to get the water locally. So the rainwater cistern system is a better way to develop irrigation in the mountainous area.
3. The extension of this techniques is warmly received by the local people. The government in various levels paid great attention to this system. A plan to support a long term drinking project using this techniques has been set up by the government.
4. The adoption of the rainwater cistern system can effectively change the backward circumstances of production and living in the arid and semi-arid area of Gansu province, China. It is regarded as a strategic measure for the economic and social development of this area.

Acknowledgment

The authors wish to express their appreciation to the Gansu Provincial Government and the Provincial Bureau of Water resources for their kind support to the experiments and the extensions. Thanks are also for the Water Bureau of Yuezhong, Tongwei, Jinyuan and Huining Counties for their hard work in sites.

References

- Waller, D.H. 1986. Rainwater—An Alternative Source in Developing and Developed Countries. Water International, 14, pp27-36

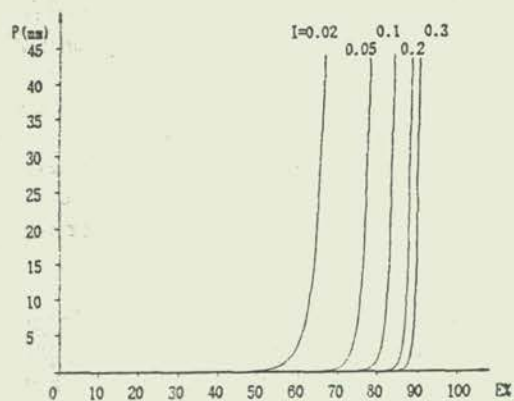


Figure 1 RCE versus rainfall amount and intensity, Tongwei, concrete

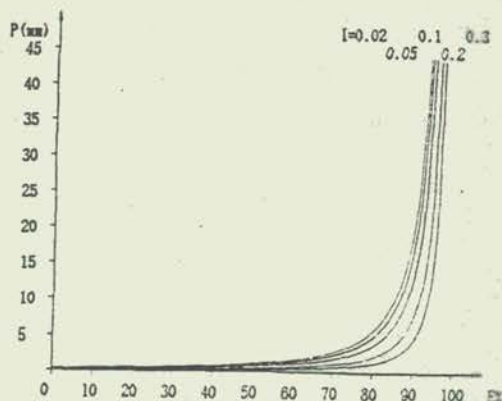


Figure 2 RCE versus rainfall amount and intensity, SMIL, concrete

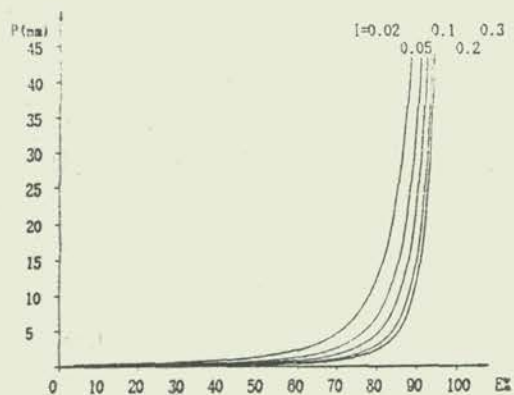


Figure 3 RCE versus rainfall amount and intensity, Yuezhong, cement tile

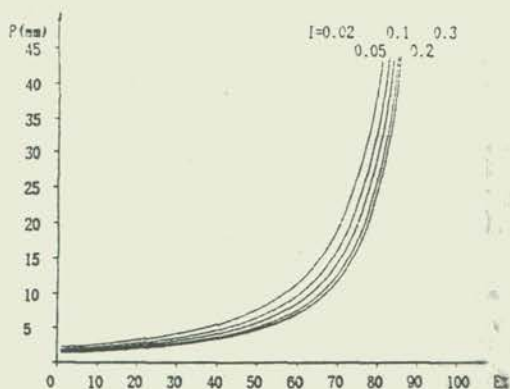


Figure 4 RCE versus rainfall amount and intensity, SMIL, cement soil

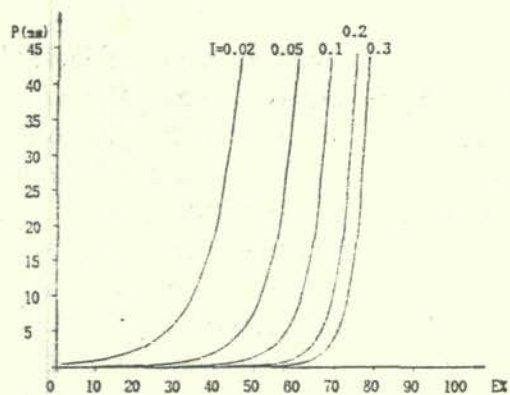


Figure 5 RCE versus rainfall amount and intensity, Tongwei, plastic film

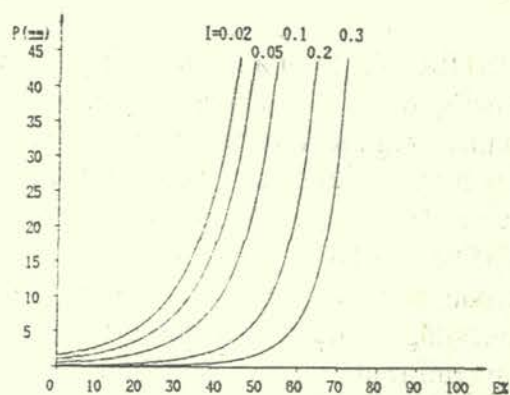


Figure 6 RCE versus rainfall amount and intensity, Shifeng, compacted loess

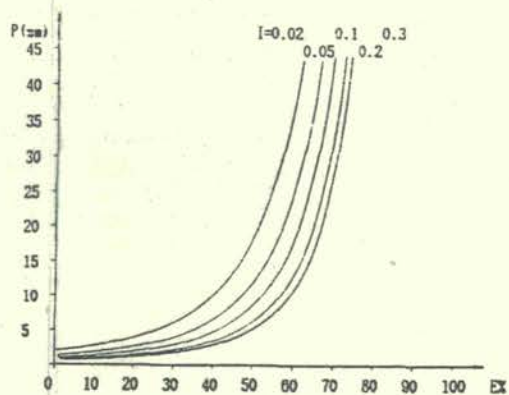


Figure 7 RCE versus rainfall amount and intensity, Shifeng, clay tile2

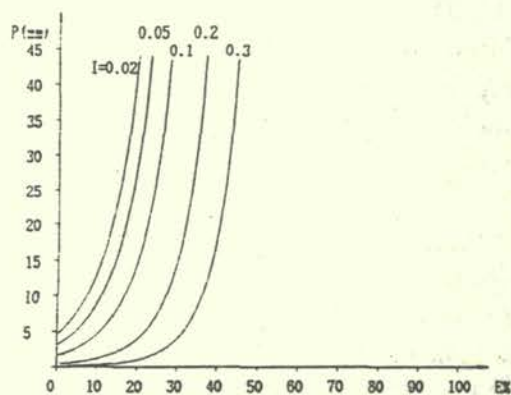


Figure 8 RCE versus rainfall amount and intensity, Tongwei, natural soil

WHY NOT HARVEST RAIN ?

J.E. Chagomelana

Senior Meteorologist, Meteorological Department, P.O. Box 2, Chileka, Malawi, Africa

ABSTRACT: Rainfall harvesting in Malawi took momentum from 1988-1989 growing season (October - April) mainly by villagers and small scale farmers in southern region areas where dryspells drought are frequent and safe drinking water is scarce. To alleviate these problems rainfall harvesting was introduced by the Malawi Government and UNDP/WMO in Agrometeorology/Data Processing project in 1988 (UNDP/WMO MLW/016). The methods of rainfall harvesting were introduced to villagers using affordable simple methods and structures such as (1) Collecting rainfall from house roofs or plain surfaces into bamboo or twig tanks (2m*1m) reinforced inside with a 2m*1m plastic tube (0.25mm thick) closed at one end; (2) Terrance farming on hilly lands to reduce run-off soil erosion and increase rainwater infiltration and (3) Horticulture pot-farming to reduced malnutrition diseases to farmers and villagers.

INTRODUCTION

The concept of harvesting rainfall in Malawi is as old as history. The Malawian people collected rainwater from house roofs into burnt earth pots (60-75 liters) for domestic use in unco-ordinated manner. As a result, much of the rainwater was wasted. To arrest the wastage of the rainwater, the Meteorological Department and UNDP/WMO embarked on the rainfall harvesting method in a project in 1988. This project covered the southern region of Malawi where many areas experience frequent dry spells (10 days or more with no rainfall or with rainfall less than 0.3mm) and agricultural drought.

RAINFALL HARVESTING METHODS IN MALAWI

(a) House roof:

House roof provide a large surface area for collecting rainwater into a cistern or water tank through a gutter connected to the roof and sloping into the cistern. This method is easy to collect clean drinking water from an bamboo mats acre spread over the roof into the gutter. And where Iron sheets gutters are difficult to obtain concrete cement or Iron sheet tanks are difficult to construct, split bamboo or wild

bush tanks are easily constructed with cheap labor and with very little cost affordable to a large population of the villagers.

In Malawi, split bamboo water tanks of 2 m * 1 m dimension are constructed reinforced with 2cm, plastic tube closed at one end slotted into the tank. The open end of the tank is protected from dust and water born diseases by a plastic tube or bamboo lid. Then the rain water from the roof through a gutter is described through a container containing three layers of sand gravel and charcoal to control the impurities. the tank holds a maximum of 1,000 cubic liters of water.

(b) Plain Surface

A plain surface made from split bamboo mat or plastic paper is mounted on four logs with one end sloping into the water tank. This method is used to supplement the collection of water from house roof into the tank or by those people with no shelter (house). The method is also employed by farmers (Small scale) and village with more than on tank below one house roof.

RAINFALL HARVEST APPLICATION

The rainfall harvested from roofs and plain surface is mainly for domestic use. But it can also be used for drip irrigation, on house hold vegetable garden and for feeding poultry and cattle. Rainfall is also harvested from run-off collected into a reservoir. The reservoir's base is covered with plastic tube or pounding low rate infiltration soil to prevent seepage. But the open top should be covered with grass to prevent evaporation. The water from the reservoir may be used for cattle feeding or small scale horticulture.

It may also be used for what is called "pot-Horticulture" (Growing vegetable around a burnt-earth pot 4-5 liters). This tilled soil at 1 meter apart. The water in the pot is refilled with less labor in about four to six days interval. And the water oozing slowly from the pot, irrigates the vegetable roots around the pot. For evaporation, the top of the pot is covered with grass lid together with mulching around the vegetable base.

(c) TERRACE FARMING

Farming on mountain slopes and hillsides is vulnerable to soil erosion and soil fertility depletion. The Ideal farming practices are those that control soil erosion,

improve water infiltration and facilitate drainage to avoid water logging. In Malawi terraces are practiced on Neno and Manza (South-western Malawi) highlands for growing crops such as beans and Irish potatoes intercropped with maize. On the terraces evaporation from soil surface is reduced by the elimination of ridges and Relay - Cropping (Planting another crop before the present is harvested) is very favorable. This is because terraces flatten the original sloping Land, thus reducing run-off but increasing the water infiltration and soil fertility retention.

The mechanism of terrace making is quite simple and is popularly known as the "Cut and Fill method. This means cutting the high ground and filling the low spots. A simple wood or bamboo " A - Frame " is used to mark the contours of the terraces.

Conclusion

The Rainfall Harvesting Project was accepted by the majority of villagers and small scale farmers. The method was easily adapted because of using. a. Simple structions: b. The drinking water and horticulture problems were alleviated and, c. No outbreaks of waterborne diseases were reported in all the project areas. At present farmers have initiated construction of permanent Ferro-Cement water tanks with bigger volume. (see appendix for A-Frame).

References:

- Rosernburg, N J 1974: Micro-climate- The Biological Environment.
- Wang, J Y 1972: Agricultural Meteorology.
- Stringer, F T 1972 : Techniques of Climatology.
- Baradas, M V 1988: Putting Hilly Land on Crop Production.

Gong Xiaohu

(Gansu Agricultural University, Lanzhou, 730070)

Abstract The precipitation in the central arid region of Gansu Province is scanty and unevenly distributed. The precipitation between November and July only occupies 20—25% of the total annual precipitation. Drought occurs frequently in late spring and early summer which has an extremely adverse effect on crop growth. In the central loess hilly region of Gansu Province, the construction of level terraced field is an effective measure to make full use of rain water, to improve production condition and to control the losses of water and soil. Diverting flood water to irrigate farmland is another effective measure to promote the development of agricultural production in the region. It not only can conserve water and soil resources and eliminate disaster but also can greatly contribute to harness the Yellow River.

Key words: Rain water use Level terraced field

Diverting flood to irrigate farmland

The central arid region of Gansu Province extends from Dongxiang and Yongdeng in the west to Long Mountain in the east and from Jingtai in the north to Longxi and Qin'an in the south. It has a total land area of 68615km² and a cultivated area of land 1.4 million ha, of which valley occupies 324000 ha, tableland 45000 ha, mountain 1.03 million ha and the effective irrigation land only accounts for 13% of its total cultivated land area. Most of the region has no irrigation condition, soil moisture can only be recharged by natural precipitation due to lack of ground water.

1. Precipitation characteristics in the central arid region of Gansu Province

1.1 Scanty precipitation and great variability

The annual mean rainfall in the region varies between 200k 4500mm, with great variability. Taking Lanzhou as an example, the precipitation in 1978 was 546.7 mm while the figure in 1941 was 210.8 mm and the maximum month precipitation might be 7 to 135 times higher than the minimum month precipitation (see Table 1). The years of below—average rainfall occupy 64% while those of above—average rainfall account for 36%. Generally speaking, every 3 years has a severe drought and every two years has a minor drought.

Table 1 Comparison of maximum month precipitation and minimum month precipitation in Lanzhou

precipitation	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
maximum (mm)	23.4	40.6	124.7	103.2	126.7	236.2	108.9	60.3
minimum (mm)		0.3	2.1	5.3	16.3	7.1	8.5	0.5
multiple difference		135.3	59.4	19.5	7.8	33.3	12.8	120.5

1.2 Annual distribution of precipitation

The precipitation in the region mostly concentrates between July and September, occupying 54—70% of the region's total annual precipitation; while the precipitation between March and May is scanty, only accounting for 10—21 % of its total (see Table 2). According to 10—day mean precipitation data

recorded at 15 stations in the region, in addition to spring drought there are two low-rainfall phases, one is in the early summer (first decade to second decade of June) and another is in the late summer (first decade to second decade of August). These are just the flowering and ear-sprouting periods of spring wheat and millet, accordingly they have extremely adverse effects on the crop growth. They are also the major reasons responsible for early summer drought and summer drought in the region.

According to the analysis on the disastrous climate between 1950k 1974, there were 17 droughts occurred in the region in 25 years, averaged once in one and one half years. In the 17 drought years, there occurred 11 early spring droughts, 15 early summer drought and 11 mid-summer droughts. Hence, the main factor affecting the agricultural productin in the region is drought.

Table 2 Month distribution of precipitation in the central arid region of Gansu Province

location	precipitation (mm)												whole year	Mar-May	Jul-Sep	remark
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec				
Dingxi	2.1	4.1	12.5	33.5	50.3	51.4	53.7	55.0	70.9	37.1	8.5	1.3	440.3	21.6	54.4	13year's mean
Gaolan	1.0	2.4	2.2	5.8	19.0	27.5	56.4	54.4	44.4	16.4	3.9	1.0	275.4	10.15	70.01	5year's mean
Yongjing	0.8	1.0	2.5	24.6	43.7	30.3	46.0	123.4	38.8	18.7	0.5	0.3	332.5	21.29	53.20	3year's mean
Lanzhou	1.4	2.3	7.6	16.7	36.0	35.6	51.8	57.4	73.6	22.2	4.1	1.4	330.4	18.25	51.44	37year's mean

1.3 Rainfall is often torrential

Rainy season in the region generally occurs between July and September, and the rainfall often falls as moderate or heavy rain. For instance, from May to September 54.3% of rainfall in Lanzhou has a daily rainfall intensity of over 10mm. Since most of the region have deep gullies with steep slopes and sparse vegetation, it easily causes surface runoff and results in severe losses of water and soil. According to field investigation data, water-eroded area in the region occupies 82.3% of the region's total land area. Maximum silt content in local rivers could reach 1000k 1200 kg/m³ and the annual erosion modulus ranged from 500k 15000 ton/km². It can be seen from this that the losses of water and soil is a serious problem in the central hilly region.

1.4 Analysis on the effective rainfall and water supply-demand situation in the crop growth period

As can be seen from Table 2, droughts in the region mainly occur between November and June, during this period the precipitation only occupies 20-25% of the annual total. The month precipitations in different years with different drought frequencies are shown in Table 3.

Table 3 Month distribution of precipitations in different years with different drought frequencies

location	frequency	Precipitation (mm)												Jan-Dec
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Lanzhou	moderate wet year	2.9	1.0	8.1	20	14.5	19.3	65.7	92.1	66.0	29.0	2.8	0.6	332
	moderate dry year	0	0.8	0.3	8.5	31.2	11.7	42.2	86.5	56.1	23.2	4.8	1.7	268
	dry year	8.3	0	8.0	14.4	31.2	42.0	77.4	30.4	8.4	15.8	0	0.5	236
Dingxi	moderate wet year	7.1	2.1	5.0	21.3	102	35.5	127.1	50.2	38.0	36.3	2.1	1.3	418
	moderate dry year	2.1	5.0	0	29.4	58.4	47.3	93.1	54.8	56.9	6.4	0	4.6	358
	dry year	0.9	2.8	8.3	8.0	24.4	57.9	38.5	38.5	108.1	11.4	9.3	0	308
Huining	moderate wet year	4.1	0.8	9.0	26.0	7.2	60.3	66.0	109.0	52.0	32.8	9.8	0	377
	moderate dry year	6.1	0	9.0	30.1	18.6	73.5	38.5	107.2	9.7	23.5	4.5	0.3	321
	dry year	4.3	9.2	6.4	35.4	30.1	18.9	26.0	64.0	42.6	13.8	4.3	0	255

1.4.1 Crop water requirement Different crops require different amount of water to produce 1 kg of grains. The water requirement to produce 1 kg of spring wheat generally ranges from 0.7k 1.2 m³ in

the region (see Table 4), and the water consumption for 1 ha of spring wheat varies between 3750k 5025 m3. However, the same crops have different water requirements in different development stages (see Table 5).

Table 4 Water consumption to produce 1 kg of grain in the central arid region of Gansu Province (m3/kg)

location	2350—3750(kg/ha)	3750—5250(kg/ha)	5250 or more(kg/ha)
Jingtai	0.97	1.016	0.68
Linxia			0.718
Dingxi		1.152	
Lanzhou—Baiying		0.758	
Mean	0.97	0.975	0.699

Table 5 Water consumption of spring wheat and its variations

location	evaporation (m ² /ha)	total water consumption (m ² /ha)	water consumption (m3/ha)				
			seedling	tillering	jointing	earring—flowering	filling—mature
Dingxi	14814	4899.6	403.2	508.8	1293.3	1515.0	1080.3
Lanzhou	12240	3009.5	131.3	522.0	882.0	1020.0	514.2
Linxia	7362	5260.5	289.5	825.0	1770.0	1110.0	1266.0
mean	10444	4607.3	285.0	688.2	1428.8	1188.8	1031.5

1. 4. 2 Effective rainfall and water consumption during crop growth period

Generally, the water consumption of spring wheat is 4500 m3/ha or so in the region, while the effective rainfall during crop growth period in the high—water year is 2065.5 m3/ha, and 2334.5 m3/ha in the low—water year. The guarantee percentage of annual rainfall, effective rainfall and the comparison of effective rainfall with water consumption during crop growth period are shown in Table 6. It can be seen from Table 6 that only by using natural rainfall can hardly meet the water demand of wheat growing in the dry—farming terraced fields.

Table 6 Guarantee percentage of annual rainfall, effective rainfall and the comparison of effective rainfall with water consumption during crop growth period

location water difference	guarantee percentage (%)	whole year		crop growth period			
		rainfall effective rainfall (m3/ha)		rainfall effective rainfall consumption (m3/ha)			
central arid region of	high—water						
	year 25	4918.5	3646.5	2632.5	2065.5	4500	—2434.5
Gansu province	normal year 50	4069.5	2877.0	2061.0	1680.0	4500	—2820.0
	dry year 75	3529.5	2502.0	1770.0	1405.5	4500	—3094.5

1. 4. 3 Soil moisture is the main water source for plant growth. Supplying adequate amount of water at suitable time could ensure the normal growth of crops and increase crop yields. In the arid region, the soil moisture content mainly depends on the natural precipitation and soil water—holding capacity.

It can be seen from above analysis that the key link to promote the normal growth of crops and increase the crop yields in the region lies in “how to store rain water after summer harvesting in soil for next spring use”, that is to say, through enhancing soil water—holding capacity and reducing soil moisture evaporation to increase soil moisture content. Practices showed that in the arid area with an annual

rainfall of less than 300 mm, building pebble—mulched field is a successful selection. This paper will discuss such problems as the construction of level terraced fields, irrigation with flood water and how to make full use of rain water etc.

2. The construction of level terraced field is an effective measure to make full use of rain water, to improve agricultural production condition and to control the losses of water and soil in the central loess hilly region of Gansu province.

Experiments and actual practices have proved that building high—quality level terraced fields in the central loess hilly region of Gansu province is an effective way to use rain water to ensure stable and high crop yields. What is called high—quality terraced field is that the newly—built terraced field should ensure to increase crop yield from the year it was built. For this purpose, it is necessary to retain as much original topsoil as possible in the terraced field, build a very firm bund 20 cm higher than the field surface, conduct deep ploughing, apply adequate fertilizer and plant suitable crops. 2.1 Using scientific farming methods to increase crop yield in the level terraced fields

Generally, the crop yield in the level terraced field is 50% or more higher than that in the sloping farmland (see Table 7). This is because the sloping farmland easily causes water—leaking and fertilizer—leaking problems. Once the sloping farmland has been turned into terraced field, the soil fertility can be enhanced.

Table 7 Crop yield comparison between level terraced field and sloping farmland

location	crop	area (ha)	terraced field yield (kg/ha)	sloping field yield (kg/ha)	yield increase (%)
Daping village, Dingxi	wheat	7.0	2448	930	163.2
Anjiabo station, Dingxi	millet	0.45	2250	1500	50.0
Nantai village, Pingliang	wheat	14.3	3264	1575	107.2

2.2 Level terraced field helps to stem surface runoff and store rain water

According to the observation data of Anjiabo Soil Conservation Experiment Station in Dingxi County, a rainfall of 101 mm with an average intensity of 23.1 mm/h occurred in June 4, 1963 was entirely collected and stored in the level terraced field (see Table 8). It may be said that the level terraced field is very like a natural reservoir without special management. Thus far, the region has built about 323000 hectares of level terraced field. Assuming that each year per hectare of level terraced field could collect about 200 mm rain water, the total water storage would be 646 million m³, corresponding to building 600 reservoirs with a capacity of 1 million m³. According to observation data, the soil moisture content in level terraced field is generally 6k 11% higher than that of sloping farmland (see Table 9). From this it follows that one of the reasons for the increase in crop yield in level terraced field lies the fact that level terraced field has a higher water—holding capacity.

Table 8 Runoff observation results at Anjiabo Soil Conservation Experiment Station

date	rainfall (mm)	mean intensity (mm/h)	water loss (m ³ /ha)		
			terraced field	9°sloping field	20°sloping field
Jun 4	101	23.1	0	371	678

Table 9 Soil moisture content comparison between terraced field and sloping farmland in Nianpan Production Team in Dingxi County

field type	depth (cm)	Soil moisture content (%)						
		Mar	Apr	May	Jun	Jul	Aug	mean
terraced field	0—10	11.94	12.81	21.02	7.25	12.19	22.23	14.57
	10—20	13.92	14.53	20.05	8.60	10.44	18.18	14.18
	20—30	14.59	14.40	19.09	9.02	9.37	14.55	13.47
sloping field	0—10	10.02	12.19	18.95	6.25	11.85	19.02	13.05
	10—20	13.40	13.90	18.03	7.32	9.37	16.00	13.11
	20—30	14.58	14.19	17.41	7.91	8.70	12.80	12.63
soil moisture increase in terraced field (%)	0—10	19.16	5.09	10.92	16.00	2.87	16.88	11.65
	10—20	3.88	4.34	11.20	17.49	11.42	13.67	8.16
	20—30	0.07	1.46	9.65	14.03	7.70	13.67	6.65

2.3 Level terraced field helps to conserve soil and plant nutrients

Sloping farmland easily causes the losses of water and soil, thus reducing the soil fertility. According to the observation data of the Dingxi Soil Conservation Experiment Station, each year one hectare of sloping farmland could lose about 1.95k 81.0 tons of topsoil, corresponding to lose about 15k 79.5 kg/ha of nitrogen or 250k 1300 kg/ha of farmyard manure. The result is just contrary in the level terraced field.

Certainly, to ensure the increase in crop yield in the newly—built terraced field, it is necessary to retain as much original topsoil as possible, increase the application rate of fertilizers and select suitable crop varieties. According to the determination results at Anjiabo Soil Conservation Experiment Station, the organic matter and total nitrogen contents in 0k 20 cm soil layer in the terraced field without original topsoil were 7.7% and 11.8% lower than those in the field with original topsoil respectively. In the terraced field with original topsoil the yields of gramineous crops increased by 5k 28% (see Table 10).

Table 10 Organic matter and total nitrogen contents comparison in the terraced fields with and without original topsoil

treatment	organic matter (%)	total N (%)	crop yield (kg/ha)			
			broom corn millet	millet	wheat	buckwheat
with topsoil	0.855	0.076	534	1411.5	594	777
without topsoil	0.794	0.068	508.5	1293.0	465.8	680.3
yield increase of former (%)	7.7	11.8	5	9.2	28	14

2.4 Deep ploughing is an important link for increasing soil moisture content and enhancing soil drought resistivity

Deep tillage is essential for the newly—built terraced field, especially at the excavated sites. Deep ploughing could enhance soil drought resistivity and crop yields, because it could promote the development of crop root systems and increase soil moisture content. Soil moisture variations under different deep—ploughing conditions are shown in Table 11. Deep ploughing can destroy plough pan, increase the thickness of loose soil layer, reduce soil bulk density, enhance soil porosity especially the non—capillary porosity, improve soil water permeability and aeration degree, reduce surface runoff and increase field moisture capacity. In addition, cutting off soil capillary can reduce soil evaporation, and thus enhances the soil moisture content.

Table 11 Soil moisture variations under different deep ploughing conditions

determination	ploughing	soil moisture contents at different depth (%)				
date	depth (cm)	0—20	20—40	40—60	60—80	80—100
Nov. 16	20	21.5	21.8	21.9	22.0	22.6
	33	23.2	23.4	23.5	22.9	22.7
Jan. 17	20	17.3	17.9	17.9	19.2	19.8
	33	20.8	20.8	21.9	21.2	22.6
Feb. 16	20	17.7	18.3	19.2	20.3	19.8
	33	21.6	22.8	22.6	22.4	22.8
Mar. 24	20	18.2	18.1	19.2	19.6	19.5
	33	18.9	17.3	20.5	18.7	18.4
May. 13	20	14.9	12.4	14.7	16.3	19.2
	33	15.3	14.2	15.9	18.5	18.8
May. 19	20	11.7	10.2	10.7	14.4	16.7
	33	13.9	13.4	15.3	17.3	17.3
May. 28	20	10.2	10.6	8.7	13.0	15.8
	33	11.2	10.4	11.7	15.2	16.4

3. Diverting flood water to irrigate farmland is an effective measure to eliminate disaster and promote agricultural production in the central arid region of Gansu Province

3.1 Characteristics of flood runoff in the central arid region of Gansu Province

3.1.1 Runoff amount

According to hydrological observation data, the flood runoff volume of the main stream system in the region varied between 12400k 38900 m³ per year, accounting for 64.6k 90.0% of its total (see Table 12).

According to the flood runoff and water erosion data observed by the Anjiabo Soil Conservation Station in Dingxi, the runoff amount in the region averaged 23059 m³/km² · yr, while the soil erosion amount was 4429 t/km² · yr (see Table 13). The actual measured flood volume roughly equaled the weighted mean value of 2.397 m³/km². Calculated by actually measured data, the mean flood runoff amount in the region is about 1500 million m³/yr, and the soil erosion amount 300 million tons or so. According to calculation data, one ton of silt in the region contains about 0.8k 1.5 kg N, 1.5 kg P and 20 kg K; and 300 million tons of silt contain 0.24k 0.45 million tons of N, 0.45 million tons of P and 6 million tons of K.

Table 12 Hydrological characteristic values of main stream system in the central arid region of Gansu province

river	observation station	catchment area(km ²)	annual runoff volume (Mm ³)	1 km ² runoff volume per year(104m ³)	1 km ² flood runoff volume per year(104m ³)	flood runoff volume percentage(%)
Wanchuan	Gaoai	131	0.025	1.91	1.69	89.4
	Jingyuan	10753	1.578	14.7	1.27	86.4
Zuli	Guochengyi	5045	0.7941	1.57	1.24	86.1
	Huining	1045	0.2311	2.21	2.01	90.9
Guanchuan	Guochengyi	3492	0.5132	1.47	1.27	86.4
	Cankou	1654	0.3734	2.26	1.46	64.6
Hulu	Qinan	9806	4.992	5.09	3.89	76.4

Table 13 Runoff observation results of small watershed

year	site	rainfall caused runoff		1km ² runoff amount (104 m ³)	1km ² soil erosion amount(t)	remark
		times	rainfall(mm)			
1959	Anjiabo.	33	348.9	25694	6025	2—watershed
	Dingxi					mean
1960	do	3	99.5	5257.5	1229	do
1963	do	6	205.8	38227	6034	13—plot mean
mean	do			23059.5	4429.3	

Above—described data showed that the major rivers in the central arid region of Gansu Province are mainly recharged by flood water. The flood water in the region is large in quantity and contains large amount of silt and plant nutrients. It can not only be used to solve the drought problem in the region but also can be used to enhance soil fertility and increase crop yields.

3.1.2 Runoff characteristics

To be able to use flood runoff in agricultural production, we must have a better understanding about the runoff characteristics. Its main characteristics are as follows:

(1) Not every rainfall causes runoff

Under certain underlying surface condition, the occurrence of runoff not only depends on the rainfall, to a great extent, it depends on the rainfall intensity and the flood runoff is generally caused by torrential rains (see Table 14).

Table 14 Comparison of the losses of water and soil under different rainfall condition

date	rainfall(mm)	runoff volume(m ³ /ha)	soil erosion amount(t/ha)
May. 23, 1963	7.3	1.3575	0.036
Jun. 4, 1963	101.4	678	123

It can be seen from Table 14 that the rainfall of the later is almost 13 times the former, while the runoff amount and soil erosion amount of the latter are 499 times and 347 times the former respectively.

The data in Table 15 showed that although the later rainfall is 39.5% higher than the former one, it does not cause surface runoff due to lower rainfall intensity. On the contrary, the former does cause surface runoff and soil erosion because the former has a rainfall intensity 8 times higher than the latter.

Table 15 Comparison of rainfall intensity and soil loss

date	rainfall	rainfall	intensity(mm/h)	runoff volume	soil erosion
	(mm)	mean	maximum	(m3/ha)	amount(t/ha)
Jul. 14, 1963	27.9	1.07	3.75	0.0	0.0
Aug. 18, 1963	20.0	5.5	30.0	75.0	8.60

(2) The runoff volume in the region has a great interannual variation and uneven seasonal distribution

It can be seen from Table 13 that both the runoff volume and soil erosion amount in the region have a great interannual variation, with a 7.3 fold maximum runoff volume difference and 4.9 fold soil erosion amount difference.

Viewed from the month runoff distribution in the region, the runoff volume in July to September occupies 55.2k 85.5% of the total annual runoff amount, while that in March to May only accounts for

1. 6k 15.9% of the total annual runoff amount.

Table 16 Month runoff volume distribution in several sites in the central arid region of Gansu province

Site	item	runoff volume (m ³ /km ²)												total	Mar-May %	Jul-Sep %
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
Lanzhou	moderate wet year					160	860	1330	3640	2310	1240			10000	1.6	72.8
	moderate high—water year					805	1769	1250	3010	4528	964	870		13200	6.5	66.5
	high—water year					166	221	1214	8372	5778	1582	810	257	18400	2.1	85.5
	high—water year															
Huining	moderate wet year					422	2567	1462	4658	3264	3655	952		17000	2.5	55.2
	moderate high—water year					950	751	3227	10984	3116	1879	1193		22100	4.3	78.4
	high—water year					1325	849	1206	8910	12518	4368	1043	391	32500	12.8	79.1
	high—water year															
Dingxi	moderate wet year					800	2820	10100	4340	1000	500	440		20000	4.0	77.2
	moderate high—water year					619	1935	9959	5549	3457	3612	571		25800	2.3	73.5
	high—water year					4600	1251	4747	7507	11224	5152	1656	422	35800	15.9	84.9
	high—water year															

(3) Small watershed is the base for sediment transportation

The region consists of many small watersheds with similar natural condition. Each small watershed consists of weir, mound, slope, tableland, platform, gully and shoaly land, which form a dendritic drainage network, with small catchment area, short slope length and great height difference. Such land-forms are good for reducing runoff loss, enhancing runoff utilization percentage and decreasing engineering cost. However, flood often occurs with tremendous power and has a short duration.

In order to make full use of flood runoff and eliminate disaster we should adopt some comprehensive measures including collecting flood water and storing flood water, with small watershed as the basic unit, to rehabilitate small watershed and according to objective conditions to develop agriculture, animal husbandry, forestry and sidelines.

3.2 Utilization of flood water

3.2.1 Diverting flood water to irrigate farmland

Practices have proved that diverting flood water to irrigate farmland is an effective measure to eliminate disaster and to conserve soil and water. In other words, it is a measure to make full use of water, soil and plant nutrient resources to increase crop yields.

(1) Storing water and conserving soil to eliminate disaster and obtain profit

Diverting flood water helps to disperse runoff, reduce flood peak and eliminate flood damages. According to the flood—diverting experiment conducted in the Neifeng Village by Pingliang Soil Conservation Experiment Station, in the 3 years the flood—irrigated farmland reached 456.9 ha, on an average, one hectare of land detained 1519.5 m³ of silt and 995000 m³ in all, thus reducing about 1.29 million tons of silt entered into the Yellow River.

(2) Increasing soil moisture and drought resistivity

Taking the experiment conducted in Sifang Village of Huining County as an example, the rainfall between November 1978 and June 1979 was 20.6 mm, in the not irrigated sloping field by flood water the crop had an irregular emergence of seedling and occurred afternoon wilting but in the irrigated field by flood water last year the crop seedlings grew well. The measured results of soil moisture content are shown in Table 17.

Table 17 Measured results of soil moisture

depth (cm)	treatment	soil moisture (%)		remark
		mid—decade of May	third—decade of May	
0—30	flood—irrigated field	9.6	9.5	irrigate on Aug. 5 last year
	non—irrigated field	7.5	7.3	
	difference	+2.1	+2.2	
30—50	flood—irrigated field	14.8	14.5	irrigated on Aug. 5 last year
	non—irrigated field	12.4	12.2	
	difference	+2.4	+2.3	

(3) Improving soil and enhancing soil fertility

According to determination data, in the flood—irrigated field the nitric—N increased by 18.3% and available P increased by 13.6% as compared with not irrigated field by flood water.

(4) Increasing crop yield

Flood water irrigation obviously improved soil and water conditions and increased crop yield. According to 3—year experiment conducted in Neifeng Village, the wheat yield increased by 36% and corn yield increased by 44.7%.

For storing flood water, it requires to set up dams and reservoirs in main gullies and lateral gullies. The water stored in high—water year can be used in low—water year and the water stored in July to September can be used in winter or March to May next year. Great attention should be paid to the reservoir sedimentation problem.

3.2.2 Prospect of flood water utilization

If the utilization efficiency of flood runoff can reach 50%, the flood water volume diverted in one hectare of land could reach 1500 m³/yr and the whole area could develop 500000 hectares of flood—irrigated land, averaging 7.3 ha/km² or 0.1 ha per person. Calculated on the basis of 3000 kg/ha, 0.1 ha flood—irrigated land can produce 300 kg grain per year, this figure is 83.5 kg higher than the per capita grain of 216.5 kg in 1979.

4. Conclusion

(1) In the central arid region of Gansu province, the major factors limiting agricultural production and economic development are drought and the losses of soil and water.

(2) Building level terraced field is an effective measure to use rain water, to conserve soil and to develop agricultural production. Deep ploughing is an important link to increase soil water—holding capacity and drought resistivity.

(3) Diverting flood water to irrigate farmland is an effective measure to eliminate disaster and to make full use of water, soil and plant nutrient resources to develop agricultural production. In the central arid region of Gansu Province, the construction of capital farmland with stable and high crop yield is of great importance. Diverting flood water, storing flood water and using flood water in the region can greatly contribute to the harness of the Yellow River.

References

1. Gansu Water Conservancy Department, A collection of soil and water conservation information, chapter 1.

2. Gong Xiaohu, Discussion on several problems concerning water conservancy construction of farmland in the loess plateau region of Gansu Province, Journal of Gansu Agricultural University, 1987, 51(3).

WEATHER MODIFICATION AS A WATER RESOURCE SHORTAGE SOLUTION IN HEILONGJIANG: POSSIBILITY AND APPLICABILITY

Jin Ying

HeiLongjiang Weather Modification Program Office
No.2 Hengshan Avenue, Harbin, P.R.China 150036

1. Introduction

HeiLongjiang province is a food base and soybean export base of China with more than 150 million acres of farmland. So the water resource especially the rainfall resource is very important for agriculture.

Weather modification is a developing technology, its basic principle is to convert vapor and liquid water in air into precipitation by exerting mechanical or dynamical influence on specific weather system artificially. Because of its great potential in solving some worldwide problems such as water resource shortage, drought, etc. and its considerable return on comparatively small investment, HeiLongjiang Weather Modification Program Office (HWMPO) has carried out weather modification theory research and flight seeding experiments for nearly 10 years.

After reviewing the conditions of water resource in HeiLongjiang, the paper discussed the possibility and applicability of applying the weather modification to fight against spring drought on the basis of analysing the macro and micro weather data of spring precipitation systems.

2. General review of water resource in HeiLongjiang

Precipitation is an important source of surface and underground water. Though it is affected by some other factors such as evaporation and seepage, water resource of a province is fundamentally controlled by precipitation conditions.

An important parameter of evaluating water resource is personal annual water quantity. It can be calculated by equation:

$$P = W/N \quad (1)$$

where $P(m^3/person \cdot year)$ is personal annual average natural water quantity; N is population of the region; $W(m^3/year)$ is total natural surface water quantity of the region, which can be drawn out by following equation.

$$W = R \times D \times 10^3 \quad (2)$$

where $R(mm)$ is annual average precipitation of the region; $D(km^2)$ denotes the region area.^[1]

Table 1 is personal annual average natural water quantity of some regions in China and the world, which is calculated by Equa.(1).

Table 1. Water resource conditions around China and world

Nation/Province	World	Japan	China	Jilin	Jiangsu	HeiLongjiang
P(m ³ /person · year)	32000	6400	5700	5136	1328	7131
Q(m ³ /person · year)	11000	4261	2700	1559	467	1546

Though China annual average precipitation is 20% more than that of the world, table 1 shows that the P value of China is only 16% of that of the world because of the huge population. Moreover, the distribution of P value inside China varies greatly. On the case of HeiLongjiang province, because of its large area and relative small population, its personal annual average natural water quantity is more than Jiangsu province which has bigger annual average precipitation than HeiLongjiang.

But inside HeiLongjiang, because population density of various regions varies greatly, the P values of them vary correspondently. Table 2 is personal annual average natural water quantity of some regions in HeiLongjiang. It shows that the water resource of some agriculture bases such as Qiqihar, Suihua, Songhuajiang are comparatively little, namely the P values of them are only 60% of national level and 50% of provincial level.

Table 2. Water resource conditions around HeiLongjiang

Regions in HeiLong- jiang province	DaXing anling	Heihe	Yichun	Mudan jiang	Jiamu si	Qiqi har	Sui hua	Songhu ajiang
P(m ³ /person · year)	68724	22458	18248	7907	7739	4121	3342	3766
Q(m ³ /person · year)	19722	6312	7693	2261	2135	741	668	1316

In fact, a considerable part of the natural water is lost by the evaporation and seepage while the seepage loss is much less than the evaporation loss. The applicable water is chiefly the runoff. Annual water reserve quantity is defined as the average of many years total runoff quantity, and it can be calculated by equation

$$Z = f \times D \times 10^3 \quad (3)$$

where Z (m³/year) denotes annual water reserve quantity, f (mm) denotes runoff depth, which can be got from following moisture balance equation

$$f = R - B \quad (4)$$

where R (mm) is annual precipitation, B (mm) is the annual evaporation which can be got from equation

$$B = [0.44RB_0(1 - e^{-0.44B_0/R}) \cdot \text{th}(R/0.44B_0)]^{1/2} \quad (5)$$

where B_0 (mm) is observing value of annual evaporation in a 20 cm diameter evaporation container, th denotes hyperbolic tangent function.^[2]

Z value of HeiLongjiang province is 5.15 billion m^3 /year.

The personal annual average water reserve quantity in tables 1 and 2 is annual water reserve quantity owned by one person. It can be calculated by equation

$$Q = Z/N \quad (6)$$

where Q (m^3 /person · year) is personal annual water reserve quantity .

Table 1 also shows that personal annual water reserve quantity of China is 1/4 of that of the world, and that of HeiLongjiang is nearly 60% of that of China. And from table 2 we know that agricultural regions of HeiLongjiang have very low personal annual water reserve quantity .

From above analysis ,it can be concluded that the water resource of HeiLongjiang is less than that of China, moreover, the great difference of that among various regions in province aggravates the gravity of water shortage problem in province.

3. Effect of climate change on water resource

Mentioned above is the general condition of water resource of HeiLongjiang. Because of climate variation, water resource fluctuates in monthly and yearly cycles. On the case of HeiLongjiang, annual precipitation fluctuates between 15- 20% in various regions and provincial average variability is 11%, but annual water reserve quantity responds to the precipitation fluctuation on a more distinct level.

Table 3. The precipitation and water reserve in water-abundant years and dry years

Items	Water-abundant years			Dry years		
	1957	1959	1960	1979	1976	1975
Year						
Annual precipitation(mm)	626	619	616	374	415	429
Relative variability(%)	+22	+20	+20	-27	-19	-17
$Q(m^3/\text{person} \cdot \text{year})$	3635	2562	3022	682	877	989
Relative variability(%)	+135	+66	+95	-56	-43	-36

Table 3 shows the precipitation and water resource fluctuations of three years with maximum annual precipitation and three years with the minimum annual precipitation between 1951 and 1980. It tells us that when the relative precipitation variability was around $\pm 20\%$, the annual water reserve quantity fluctuated between -60 — +140%.

When annual precipitation was 20% short, annual water reserve quantity would be 40% short.^[3]

Table 4 is the relation between the variabilities of the annual water reserve quantity and precipitation of consecutive 2, 3, 4, 5 years in water-abundant period (50's to 60's) and dry period (70's). From the table 4, it can be deduced that successive dry years would cause successive 30-40% reduction of annual water reserve quantity. As a result, underground water level and surface water level would drop.

Precipitation also fluctuates seasonally in HeiLongjiang. According to the statistics of precipitation data from 1951-1980, summer precipitation was 64% of annual rainfall, fall was 18%, spring was 14%, winter was 4%. So, spring is dry. In addition, spring is windy and evaporation is big. As a result, water reserve is in short for the agriculture.

Table 4. Precipitation variation and water reserve variation of consecutive water-abundant years and dry years in HeiLongjiang

Items	Consecutive water-abundant years				Consecutive dry years			
	2 cons Yrs	3 cons Yrs	4 cons Yrs	5 cons Yrs	2 cons Yrs	3 cons Yrs	4 cons Yrs	5 cons Yrs
Years	1959- 1960	1958- 1960	1957- 1960	1956- 1960	1978- 1979	1977- 1979	1976- 1979	1975- 1979
Annual average precipitation(mm)	618	569	583	586	409	435	430	430
Relative variability(%)	+20	+11	+13	+14	-21	-16	-17	-17
Q(m ³ /person · year)	2799	2344	2677	2760	884	1091	1038	1029
Relative variability(%)	+81	+52	+73	+79	-43	-29	-33	-33

4. Contradiction between agriculture and natural precipitation

The required water quantity in growing period of many crops is a variable in connection with rainfall, temperature, sunshine and evaporation. According to the

research of the maximum output and water quantity required of various crops(Qi,1984)⁽⁴⁾ when every credential is fulfilled, as shown in table 5, annual average precipitation in HeiLongjiang is not enough for the requirements of crops. The situation would be worse in dry years.

Table 5. Water requirements of crops growth and precipitation in agriculture bases of HeiLongjiang

Crops	wheat	Soybean	Corn	Potato
Growth months	3-8	4-9	4-9	4-9
Maximum output(jin/acre)	500-800	300-400	500-800	4000-5000
Required rainfall(mm)	450-650	450-700	500-800	500-700
Harbin	402	451	451	451
Suihua	424	475	475	475
Qiqihar	336	376	376	376
Nenjiang	372	427	427	427
Jiamusi	395	449	449	449
Mudanjiang	396	442	442	442

To solve problems mentioned above, there are two ways:

- 1). Irrigation. It is inapplicable in HeiLongjiang because:
 - a. HeiLongjiang has too much area of farmland to be covered by irrigation network.
 - b. HeiLongjiang lacks water resource.
- 2). Weather modification. As discussed above, precipitation variation will cause greater variation of water resource. Hence, artificial rain enhancement operation can increase water resource significantly. If precipitation can be increased by 20 mm within a vast areas, water reserve quantity will be increased by around 10%. Weather modification can also play an important role in fighting against drought. It will increase effective rainfall acquired rate of the farmland by applying operations at the key time in growing period of the crops. Generally speaking, loss rate of ridge irrigation is around 30-60%, and that of spray irrigation is about 15-20%. On the other hand, 20-40 mm precipitation in dry farmland will be absorbed completely. So, weather modification will be one of the most effective ways to solve the agriculture water problem if it can be combined with some technologies such as loose soiling.

To apply the weather modification in practice, we need to know :

a. Seedable weather pattern;

b. Seedable microphysical structure.

We will discuss these questions in following passage.

5. Analysis of favorable weather for weather modification in spring

Spring in HeiLongjiang is from April to May. We mainly discuss the precipitational processes in some major food bases of the province including Qiqihar, Suihua and west of Songhuajiang where drought often breaks out. The process selection standard is : when the daily precipitation (20:00 -20:00, Beijing Time) is no less than 10mm in the regions mentioned above, the day is counted as a heavy precipitation day (HPD).

5.1 Number of HPD

Between 1960 and 1984, there are 40 HPDs in April and 64 HPDs as shown in Table 6.

Table 6. Number of HPD in April and May

Year	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
HPD in Apr.	1	2	0	3	1	2	5	1	4	2	0	0	1	1	0	0
HPD in May	4	3	0	2	0	1	0	6	1	0	3	4	3	2	4	3
HPD in Apr.&May	5	5	0	5	1	3	5	7	5	2	3	4	4	3	4	3

76	77	78	79	80	81	82	83	84	Tot	Ave
2	1	3	1	2	2	1	4	1	40	1.0
3	2	3	1	4	2	7	4	2	64	2.6
5	3	6	2	6	4	8	8	3	104	4.3

In Table 6, we can see that in spring HPD is very few. On the one hand, it shows the necessity of weather modification in spring, on the other hand it shows the difficulty of catching the opportunity of weather modification operation.

5.2 Feature of HPD

Table 7. Feature of HPD in April and May

Rainfall feature	April		May	
	Days	Rate	Days	Rate
Consecutive rain	32.5	83%	40.5	63%
Intermittent rain	4.5	12%	5.5	8%
Shower	2	5%	18.5	29%

Stratiform cloud causes consecutive and intermittent rain while convective cloud causes shower in spring.

In Table 7, heavy precipitation in spring is chiefly from stratiform cloud, 96% and 71% in April and May respectively.

5.3 Source of surface precipitational system

Table 8. Source of surface low pressure system

Surface low pressure system	April		May	
	Num.	Rate	Num.	Rate
Mongolia	16	53%	26	50%
Northeast	6	20%	15.5	30%
Hetao	5	17%	4	7%
North China	1	3%	1.5	3%
Jianghuai			1	2%
Baikal Lake	2	7%	3	6%
Frontogenesis			1	2%

In Table 8, the surface low pressure systems causing heavy precipitation in Heilongjiang includes Mongolia system which constitutes 48-53% of precipitation processes, Northeast system which constitutes 20-30%, Hetao system which constitutes 7-17%. Among them, Northeast system is newly developed, and once it forms, it will bring heavy precipitation to province.

5.4 Direct influential systems causing HPD

Direct influential systems causing HPD are classified into upper systems such as trough and vortex, and surface systems such as warm front, cold front, occluded front, central depression, warm sector, secondary cold front.

Table 9. Surface influential systems

Surface influential systems	April		May	
	Num.	Rate	Num.	Rate
Warm front	11	28%	17.5	27%
Cold front	4.5	11%	9.5	14%
Occluded front	8	21%	13.5	21%
Central depression	8	21%	16.5	25%
Warm sector	7.5	19%	3.5	5%
Stationary front			2	3%
Secondary cold front			3	5%

In Table 9, major surface influential systems causing HPD includes warm front which constitutes 27%-34%, occluded front which constitutes 21%, central depression which constitutes 21-25%. The other ones have little influence.

Table 10. Upper direct influential systems

Upper direct influential systems	April		May	
	Num.	Rate	Num.	Rate
Trough front	13	34%	10	15%
Transversal trough			3	5%
Ridge front			1	1%
North ridge south trough			10	15%
Vortex	25	66%	42	64%

The systems here denote the ones on 700hPa map.

In Table 10, vortex constitutes 64-66% of all systems. It includes Baikal vortex, Mongolia vortex, Hetao vortex, North China vortex and Northeast vortex which developed from trough. Troughs include Mongolia trough, Hetao trough and North China trough.

6. Analysis of microphysical structure and process inside cloud with seeding potential

Deep stratiform cloud system has both warm cloud and cold cloud, so it can be classified as combined cloud. The precipitation mechanism of the cloud is the

association of the warm precipitation mechanism and cold precipitation, and it can be called combined precipitation mechanism or "seeder-feeder" mechanism. Generally, the combined cloud has three layers with regard to height and temperature: upper layer ("seeder") that the temperature is below -25°C to -30°C , it has high ice crystal concentration; middle layer that the temperature is below 0°C , ice crystals and supercooled water coexist in this layer; lower layer ("feeder") is water-abundant cloud that the temperature is above 0°C . After sublimation growth in "seeder", ice crystal falls into middle layer and continues to grow to $100\mu\text{m}$ or bigger by ice-water conversion process, then it grows by riming the abundant supercooled water. Once falling into "feeder", the ice crystal melts and starts collection growth process until it falls out of the cloud.

According to north China stratiform cloud research program (You, 1992)^[6], most of the heavy precipitation from stratiform cloud in north of China can be attributed to seeder-feeder mechanism. In HeiLongjiang, the cloud physics concept model of precipitation system is shown in Figure 1.

Table 11 is the microphysical parameters of the flight seeding operations in HeiLongjiang in spring during 1989-1992. From it, we can see that the LWC (liquid water content) in "feeder" cloud layer in most cases is ample, in average more than $0.1\text{g}/\text{m}^3$. The ICC (ice crystal concentration) on the top of "feeder" cloud is around $0.4-70 \times 10^3/\text{m}^3$. According to Zhao and Ding (1963)^[6], in terms of theory, it requires ICC to reach as much as $100 \times 10^3/\text{m}^3$ scale to get the maximum precipitation rate from the open frontal stratiform cloud system when the upflow velocity is $0.1\text{m}/\text{s}$ and LWC is $0.1\text{g}/\text{m}^3$. So, the ICC in HeiLongjiang stratiform cloud is lower than the theoretical value, namely, the cloud has seeding potential. If we introduce proper artificial nuclei such as AgI into the proper position of cloud to compensate natural ice nuclei, we will probably convert more cloud water into surface precipitation. According to the statistics of aircraft cloud-seeding operation cases during 1988-1992 in HeiLongjiang, when we seeded $10^3-10^4/\text{m}^3$ AgI nuclei on the top of the "feeder" cloud whose thickness was $>2\text{km}$, the increase of surface precipitation rate could be 10-30%, but when seeding position was in the "feeder" cloud or artificial nuclei quantity was more than $10^4/\text{m}^3$, the result was not significant, in some cases even negative. By our assumption, it is because that artificial nuclei increase the number of total cloud drops and decrease the opportunity for the single drop to grow to precipitable size through collection process in "feeder" cloud.

7. Conclusion

From analysis above, we have following conclusions:

- 1). HeiLongjiang is a water shortage province.
- 2). The distribution of water resource in HeiLongjiang is not even, in some agriculture bases the water resource is lacking.
- 3). Spring, the key period for seeding crops, is often dry.
- 4). Annual average of HPD in spring in HeiLongjiang is around 2-6 days.

- 5).Most of HPDs in spring are from stratiform cloud which is suitable for air seeding operation.
- 6).The chief surface low pressure systems causing heavy precipitation are Mongolia system, Northeast system and Hetao system.The chief upper systems are vortexes, correspond surface systems are warm front, occluded system and central depression.
- 7).The chief mechanism controlling spring precipitation in HeiLongjiang is combined mechanism .
- 8).The natural ICC in "seeder" of the stratiform cloud is little in comparison with the LWC in "feeder", estimated to be one scale in short for the maxium precipitation requirement.Consequently,the seeding potential in stratiform cloud is big,in HeiLongjiang the natural precipitation can be enhanced 10-30% by flight seeding.

References

- [1].Ding Shicheng,1982.Climate and water resource,Meteor.Monthly,Vol.10,No.11.
- [2].Gao Guodong,et al,1980.Research on land surface evaporation and heat evaporation in China,ACTA Meteor.Sinica,Vol.38, No.2
- [3].HWMPO,1991.Research on weather modification technology system, Meteor. Press, 147-151.
- [4].Qi Laifu,1984.Progress on relation of crops production to water content in abroad, Special Issue,Shanxi Meteor.Tech.
- [5].You Laiguang,et al,1991.The Collection of North China Stratiform Precipitation Research:Scientific Report,4-11.
- [6].Zhao Bolin,Ding Rongliang,1963.ACTA Meteor.Sinica,Vol.33,No.3.

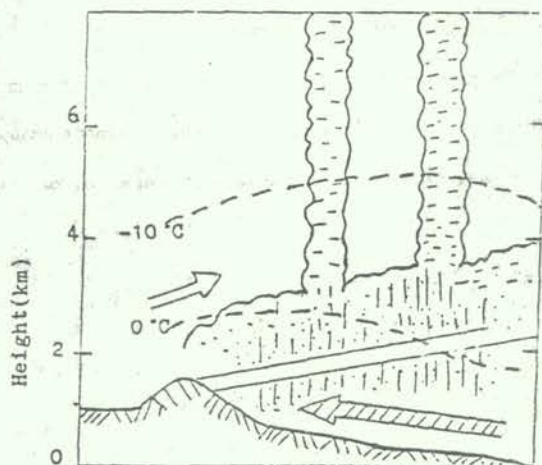


Figure 1. Concept model of precipitation system in HeiLongjiang
 Slice denotes ice region, dot denotes water region, strip denotes precipitation,

Table 11. Microphysical parameters of flight seeding clouds during 1989-1992 in Heilongjiang

Seeding C dates	Cloud Seeding types height(m)	Cloud bottom Seeding height(m) temperature(°C)	Cloud bottom temperature(°C)	Cloud top height(m)	Cloud top temperature(°C)	Cloud thickness(m)	LWC (g/m ³)	IC (10 ⁶ /m ³)
5/19/89	Sc,As 3500	870 -2.3	12.6	4500	-9.0	3630	0.05	21.4
5/26/89	Cl,As,Ns 3000	600 -2.0	14.2	4000	-7.5	3400	0.08	15.0
6/19/89	As,Ac,Sc 4500	1500 -7.9	6.6	5000	-8.6	3500	0.12	23.4
5/09/90	Sc,Ac,Fc 3500	1000 -3.2	11.5	5200	-16.4	4200	0.21	47.2
5/11/90	Sc,Fs \	1300 \	1.1	4500	-18.0	3200	0.03	27.9
5/14/90	Cl,As,Ac \	2500 \	-2.9	6000	-24.1	3500	0.01	57.7
5/19/90	Ns,Acop 4000	1500 -5.6	8.3	4600	-9.2	3100	0.17	25.0
5/20/90	Sc,Asop 3500	1000 -3.6	8.0	4500	-14.0	3500	0.21	18.5
5/21/90	Ns,Fn 3800	500 -4.8	6.5	4600	-10.7	4100	0.33	55.7
5/26/90	Sc,As,Ns 3000	1800 -2.1	9.5	4300	-6.2	2500	0.14	11.7
5/29/90	As,Fs 5000	600 -8.9	14.2	5000	-8.9	4400	0.10	17.9
6/09/90	St,As 3800	800 -2.7	12.6	5000	-7.5	4200	0.37	55.1
6/02/92	Cl,Sc,As 5500	1100 -9.5	15.0	5500	-9.5	4400	0.28	15.3

Notes: Sc denotes stratocumulus, As denotes altostratus, Ac denotes altocumulus, Ns denotes nimbostratus, Ci denotes cirrus, St denotes stratus.

Fs denotes fibrous stratus, Fc denotes fibrous cumulus, Fn denotes fibrous nimbus, Asop denotes altostratus opacus, Acop denotes altocumulus opacus.

CONSTRUCTION OF PLAIN DRAINAGE SYSTEM FOR A GOOD USE OF RAINWATER

Baohong Lu Kailin Wang
(Water Conservancy Office, Xuzhou City)

Kejian Cai
(Water Conservancy Office, Tongshan County)

To the south-east of Tongshan County, Xuzhou city, there is a plain, which locates at the upper reaches of Huaisui river, a branch of Huai river. It was an alluvial region of Yellow river in history, with low terrain and underdeveloped economy, suffered from severe water-logging, drought and salinization of soil, people's life was very difficult there after forty-year's comprehensive control and development, drainage system in the plain is accomplished and a good use of rain water is realized. Additionally, combined with the water transfer from south to north and regulation of crop distribution, the capacity of drought resistance is raised and the condition of water use is improved. The past wasteland is change into the beautiful and rich "place of fish and rice" in the north of Huai River.

The process of how to make a good use of rainwater for a rapid development of local economy, as well as the experience of searching out an appropriate way for rational utilization of rainwater resources, is described in this paper.

I. General survey of the plain.

The plain is to the south east of Xuzhou city, southward contiguous to Anhui Province and eastward facing Suining, including five townships of Tongshan county: Pantang, Zhangji, Fangcun, Tangzhang and Guoji, and with a total area of 367km², farmland of 36200Mu (667m²), population of 215000. In the plain, Xu-Huai road goes through from east to west, and the terrain is low in the northwest and high is the south east. Its altitude is *31-*228. The chief rivers form west to east are: Langxi, Yanxi, Kanxi, Qingxi, Yunliao and Shenjia gou etc. Its local climate belongs to semi-humid monsoon climate of warm temperate Zone, which is characterized by obvious temperature change. The normal annual, average of air temperature is 14.30C, of evaporation is 902mm, of precipitation is 852.6mm. According to extant documents, the maximum of annual rainfall is 1360mm(1963), while the minimum is merely 568.4mm (1988). Rain mainly occurs in the period from June to September, which accounts for 66.8% of the total annual rainfall. As a result, disaster caused by storing frequently occurs in summer, while water shortage caused by drought often takes place in wither and spring. Vegetation is extremely poor and the salty land accounts for 43.06%, moreover, 9.6% of which is high salinized land. In history, from 1194 to 1855,

Yellow River over flowed for quite a few times in the period more than 600 years. In addition to continuous wars, river channels were out of repair, forest was destroyed completely and disaster of storm, drought, sand and salinization was very frequent. In the period from early Qing Dynasty (1659) to new China founded (1979), severe water-logging took place for seventy-two times and serious drought occurred for twelve times. In this plain, which locates below the banks of Yellow River, rain is deficit generally and river is replenished inadequate. Additionally, there was no water source form outside. So, the resistance capacity of drought or flood was very low. When drought happened all over the plain was under the arid disaster, while in flood season, since lower reaches was seriously choked with silt, the detained water can not be discharged in time. So, the damage caused by water-logging had become more and more serious and soil fertility had become lower and lower owing to the ever-aggravating salinization. In many plots, the thickness of salty powder reached 1-2cm. Therefore, the growth of crops were severely affected, and wheat yield was merely dozens of Jin(0.5kg). People's life was very miserable, Some of them left away from their homelands as beggars and some lived by selling nitric salt.

II. Searching for controlling way

After the New China founded, the government cares for people's life and pays attention to the mass request for controlling the disaster of water-logging and flood, improving productive condition and living environment, and have made the construction of water conservancy in a great scale. Having practiced for forty years, experience of controlling has been obtained continuously from successes and failures, and relatively perfect way of controlling, which is rainwater use, comprehensive control, developing economy and improving environment, has been gradually formed. It is a successively developed and enhanced procession of understanding, countermeasure and benefit, which can be approximately divided into following three stages. First stage c 50's-60's); according to the situation of storing , flood and water-logging in flood season, beginning with the control of flood and water-logging ,taking soil change and water control as key point, projects of channel dredging have been carried out in a large scale. many major rivers have been dredged early on later such as Langxi, Yan, Yunliao, etc. Meanwhile, ditches have been made in farmland for controlling water logging, However, because the standard of ditch was low at that time , additionally, this region locates at the juncture of Jiangsu and Anhui Provinces. flood discharging is still difficulty in the lower reaches, and some village still be flooded when storm accure. Government in each level pays much attention to soil improvement. In the late 50's, experimental station of saline-sodic soil amelioration, which belongs to soil institution, College of Agricultural Sciences , Jiangsu Province, was established in Zhangji town ship. Various experiments were carried

out in early time or late, In 1958, Soil of tableland was changed in large areas, that is digging clay soil out from a area of 20 X 20m² to cover saline-sodic soil, and only in the same year, crop yield was raised for saline and alkali came out in the next year. In 1960, strip checks were made and gutters were formed with a space of 30m between gutters. However, the effect of salinization control was not remarkable owing to the unstable distribution of rainfall in space and time . In 1963, green manure crops were applied in large areas , and rotation system of food crops and green manure crops was performed, but the effect was not remarkable.

Second stage (70's -the early of 80's):key point in this period was change of cropping system. Rice was planted in large area of farmland ,and much arid land was changed into paddy land. Paddy field was enlarged to 200000 Mu (667m²) in the end and agricultural water requirement increased rapidly. In order to solve the problem of water shortage, rainwater use was placed at the most important position in construction of water conservancy. Six small reservoirs have been built along the south bank of Yellow River. However, these reservoirs rarely had full storage because Yellow River's basin is narrow and small, additionally, much water was stored and diverted in the upper reaches. Therefore, the contradiction between water supply and demand was still serious in a drought year. In the middle of 70's, two middle pump stations were constructed and enlarged, which were used for water transfer form the Grand canal to the reservoirs to solve the problem of inadequate use of rainwater. AS much dry land were changed into paddy field and large quantity of water was required for irrigation, much salt and alkali were washed away or assimilated by crops. additionally, organic fertilizer was raised rapidly, Soil texture was improved, and further, grain yield was increased rapidly. Especially in this region with a non-frost period less than 210 days, the success of experiment on double cropping of rice and wheat raised crop yield approximately to 1000kg/Mu. Construction of water conservancy was promoted by -the change of cropping system, and a beneficial cycle of cropping system change---construction of water conservancy---rainwater use---Soil amelioration ---increase in crop yield has been formed. However, because water transferred from the Grand Canal was of low reliability the problem of water shortage was not solved completely. As a result, the area of paddy field often fluctuated and, agricultural economy was still impeded from rapid development.

Third stage (the early of 80's-nowadays);The project of water transfer from the long river to the north in Jiangsu Province, which starts from Jiangdu pump station, along with the Grand Canal, finally to Xuzhou, has been accomplished. It has realized inter-basin water transfer and rainwater use and control, mitigated the problem of Water shortage. In many townships Such as Tangzhang etc. drainage system construction has been carried out for a good use

of rainwater and development of irrigation. Additionally, in the stage, taking advantage of the Loan from International Bank for agricultural irrigation development, project of "changing waste-land into paddy field" has been performed in Zhangji, Tang-zhang, Fangcun townships etc, in a large scale, Water-saving irrigation techniques have been widely popularized, and ecological environment controlling model, which includes building drainage, system making a full use of rain water for irrigation, ameliorating soil texture, raising the rate of vegetation cover, has been established.

Based on the great change of farming condition, agriculture of high crop yield, high quality and high profit got a rapid development and soil got remarkable amelioration. Instead of salinized field in the past, these five townships developed rapidly and were famous for their "silkworm", "cow", "vegetable", "Poultry and egg", and "cotton" respectively. In addition to the rapid development of agricultural processing, this region became beautiful and rich modern villages. In 1994, total crop yield reached 131200 tons, total cotton field was 2365 tons, total output value of industry and agriculture together is 155000000 Yuan, in which, total output value of agriculture was 556000000 Yuan. The annual average income of each people reached 1403 Yuan, which was most increased by ten times of that, in the early of 60's after deducting the factors of inflation and price rise.

III. Main Experience

Practiced for forty year, the model of rational utilization of rainwater and agricultural development has been gradually formed, and the key points of the experience are:

1. building plain river net to form a system of water conservancy engineering, which includes water storing, draining and transferring making a full use of rainwater.

Firstly, building plain step river net gradually around major river channel. The depth of river channels and ditches is required no less than two meters below normal water level, and it is sure that major rivers as well as middle ditches are filled with water throughout the year. Certain capacity of storing, diverting, draining and exchanging between surface water and ground water is required. Generally, channels and ditches are formed with flat bottoms. According to topography they are controlled in different levels. Owing to the degree of slope is small in this region, height difference between different levels is 1.5-2.0 meters. The most important feature of this region is that it locates at the juncture between different province, and channel standard in the lower reaches is low, In order to enhance the capacity of water storing and make a good use of rainwater for irrigation, river beds are broadened and strip river bed reservoirs are formed. River bed section is designed based on the standard of water storage, which is 30-

50m³/Mu in dryland and 100-120m³/Mu in paddy field. Water storage capacity of each township is 3-5 million m³ and rainwater use efficiency is more than 80%. Moreover, flood is mitigated in lower reaches even in a extremely heavy storm.

Secondly, constructing engineering network of drainage and irrigation, reusing irrigation returning water and raising rainwater use efficiency.

Thirdly, building regulating dams and pump station for inter basin water supply. Due to the limited water storage of river channels, the problem of water shortage in a drought year or rice planting season is still serious. Taking advantage of the topographic feature of this region that the abandoned river bed of yellow River is 4-5 meters higher than ground surface, six man-made dams have been built with a water storage capacity 3-6 billion m³ each to harvest the rainwater from the abandoned flood land of Yellow River, Meanwhile, a water pump station with a discharge of 20m³/s has been built at the north side ,by which much water is pumped form the Grand canal and Fangting river to the man-made dams in winter and spring except the irrigation of 157000 Mu wheat land and rice planting of more than 100000 Mu paddy land is satisfied. Since the middle of To's, each year 70 million m³ water is supplied for this region through Wangshan Pump station .Since the middle of 80's, cascade pump station for water transfer has been accomplished. up to the early of 90's, Xuhong River has been joined up . There fore, interbasin water transfer and rainwater use are realized in Xuzhou city.

Fourthly, surrounding low-lying fields with dykes carrying out gravity drainage and pump drainage. Pump station is built in large gullies, which has the function of both irrigation and drainage. Sluice gate is installed at the month .when storm or water logging, which is beyond the criterion of gravity drainage, happens, pump begins to work and drains water from the surrounded low-lying field. meanwhile, pump station is planned to be built at the upper reaches of major rivers, when flood can not be discharged in time into the lower reaches, much water is pumped into reservoirs and stored for irrigation.

Fifthly, controlling by cascade sluice gates and realizing rational management of water resources. After cascade river net is finished, some new problems will be brought about . Such as, contradictions between water storage and drainage, between continuous water storage and salinization of soil caused by the rise of groundwater level. It is proved by practice that these contradictions can be solved by controlling works and rational management.

2. Combining rainwater use with cropping system change and agricultural structure adjustment. Construction of water conservancy system in this region has been pushed forward and deepened by the change of cropping system. It is shown in practice that changing dryland into paddy field is the only way for making a good use of rainwater. Therefore, based on the local condition and in accordance

with the water requirement of rice, an rational water conservancy system has been established in turn, the established system solidifies the achievement of cropping system change, Water logging resistance of rice is relatively strong. In a storm ,when rice is inundated for 3-5 days, its Field is affected little as long as a good field management is carried out after water subsides. There fore, the pattern of cropping system change and water conservancy projects is relatively stable, the rate of rainwater direct use is raised when paddy field is enlarged. Additional , the period of water demand for paddy land irrigation is in a good agreement with the local rainy season. So, in the region ,water requirement of paddy land irrigation is even less than that in the areas along Changjiang River. Along with the development of rural economy and the requirement of increasing farmer income, agricultural structure has been regulated for second time in this region. On the condition that the area of paddy land is stable, the field area of cotton, mulberry and vegetable is increased rapidly. original river net not only provides good condition for drainage and irrigation ,but also provide land for commercial crops after dredging, and the agricultural profit is raised greatly. It not only arouses farmer's enthusiasm for construction of river net, but also promotes the application and development of new irrigation techniques. The control pattern and its effect of experimental land for changing the waste land into paddy land in Zhangji township is affirmed and praised by the central committee of the party and the Agricultural Development of Jiangsu Province.

3. Soil amelioration requires the combination of biological measure, engineering measure and the system of drainage and irrigation .Comprehensive control ,which includes rational use of rainwater for irrigation, soil change ,flood control and afforestation . is also indispensable for soil amelioration .It is proved by practice that rainwater use is the most effective way for soil amelioration. The improvement of salinized soil of large area in the region is largely attributed to rice planting. Taking cropping system change as the key point, a remarkable achievement is obtained through comprehensive controlling measures. The main measures are:

- (1) Drainage and irrigation are separated in engineering distribution.
- (2) Monitoring water quality and transferring water from outside frequently.
- (3) Cotrolling storage water level by river net and controlling the buried depth of ground water no less than 1.5-2.0m to protect soil form salinization.
- (4) Carrying out crop rotation in dryland and paddy land with a rotation cycle of 2-3 years against the upraise of salt.
- (5) Combining afforestation with the construction of plain river net and farmland to form space forestry net.
- (6) Replacing planting green manure crops in land by returning the straw of wheat rice to land. planting green manure crops can improve soil fertility,

However, it also affects crop yield. So, it is difficult to be popularized under the circumstance that farmland is ever-decreasing. After cropping system has been changed into double cropping of rice and wheat, much straw is produced, which is fermented and applied to land as rotted manure. Therefore, soil organic matter content is increased. Quite a few of Large farms of cow, pig and chicken have been established in this region, and the famous company, "Wei Group" in Jiangsu province, takes this region as the source of its raw material.

4. Making an unified plan, Carrying out diversified economy and implementing by stages.

Using rainwater to reform the natural environment and develop economy is a very complicated systematic engineering. It is indispensable to have an unified plan and take the comprehensive control of "flood, water-logging, arid, salinization", and "hill, water, Land, forest, road", combine with rural construction and economic development and have a distinct objective. It is estimated that reaching a high standard of drainage system construction, the cubage of excavation if farmland reaches $70-80\text{m}^3/\text{Mu}$, and the cost of building as well as motor pump ect. is 400 Yuan/Mu. Calculated with the area of arwland, which is regard as much as 300000 Mu in the region, the total cubage of excavation is 24 million m^3 , and the total cost reaches 120 million Yuan. Due to the underdeveloped economy and weak foundation in this region, labor service is the main investment. IN the past thirty years. the accumulative cubage of excavation reaches 20 million m^3 and the accumulative raised funds reaches 60 million Yuan, total capital investment in chiding the allowance form governments in each level reaches 30 million Yuan. Up to now, 70% of total investment in plan has been accomplished.

IV. Conclusion

Making a full use of rainwater is still an important way to improve farming condition, ameliorate ecological environment and promote the development of economy in the north of Fluaihe river. It is of great importance to find a feasible, rational model for control and development in accordance with the local condition. Additionally, in order to attain the goal of effectively reforming the natural environment. promoting economic development and enhancing the level of people's life, it is indispensable regarding the model as a whole ecological body and systematic engineering having an unified plan and comprehensive control, implementing it by stages.

Technical development of rainwater catchment systems

by Isao Minami

President of Japan-IRCSA

Water resources development of rainwaters from roofs, buildings, pavements of roads, limited area of ground is very important from the stand points of good water, natural resources and environment. This idea can be realized through the study and adoption of an integrated rainwater catchment system.

Many areas of the globe still remained as water resources limited areas due to lack of big rivers and groundwater.

At times, we have the opportunity to discover the great needs of rainwater catchment systems such as during serious drought (return period longer than 10 years) or serious disaster at big modern city by earthquake.

The technologies of integrated rainwater catchment system might be accepted in more wide areas in agricultural, domestic and industrial regions in the world. This will be especially so, when the modern water resources systems break down due to unusual drought, not only in rural areas but also in modern cities.

To serve this point, it is very important to develop an integrated technology of rainwater catchment systems not only in developing countries but also in developed countries.

The unusual shortage of water can be understood more clearly by the following equations.

$$\begin{aligned} \text{Unusual shortage of water} = \\ \text{no facilities} - \text{water consumption} \end{aligned} \quad (1)$$

$$\begin{aligned} \text{Unusual shortage of water} = \\ \text{insufficient water resources facilities} - \text{water consumption} \end{aligned} \quad (2)$$

$$\begin{aligned} \text{Unusual shortage of water} = \\ \text{modern water resources facilities} - \text{water consumption} \end{aligned} \quad (3)$$

(return period 10 years)

Integrated rainwater catchment systems will also help in the unusual serious water shortages.

1 Origins of rainwater to collect.

- (1) Roof rainwater from a private house and clusters of private houses.
- (2) Group of roofs of public buildings, schools and factories and blocks in cities.
- (3) Rainwater from artificial tent.
- (4) Rainwater from paved plane.
- (5) Rainwater from side ditches of roads.
- (6) Run off from small valleys.
- (7) Water from melting snow at small valleys.
- (8) Rainwater on a rainfed paddy rice field
- (9) Effective rainwater on a paddy rice field

2 Water harvesting technique

Water harvesting techniques to intensify rainfall on the cropping area should be studied more scientifically. For example, the intensity of rainfall on A0 can be increased to N times the original rainfall, if rainfall is collected from "A0" and only crops from a smaller area A, that is one on N of area A0. This rainwater should be stored underground during the life period of the crops.

New techniques of rainwater harvesting for agricultural crops must be developed.

- (1) Rainwater can be stored in the soil of upland, in rainfed paddy rice fields.
- (2) Rainwater can be stored in the ditches, canals and depressions.
- (3) Intensification of rainwater with wider rainfall receiving area and narrower cropping area.
- (4) Development of rainwater intensification apparatus for crops cultivation at desert area.

3 Water quality control of rainwater

The quality of rainwater should be improved at storage before utilizing it accordingly for its various purposes.

- (1) Improvement of the acidity of rainwater through flow in the ground.
- (2) Neutralization of the acidity of rainwater in storages by having a filter with gravel of limestone in it.
- (3) All lights should be shut out in the storage container to prevent planktons in water.

- (4) Kill the bacteria of rainwater by boiling before drinking.
- (5) When much rainwater can be stored in dam, a modern water treatment machine can be recommended.
- (6) Rainwater can be stored in a tank which is constructed underground of a house.
- (7) Dusts should be eliminated through the filter in storages or through selective bottom water drainage system (syphon spill way) before using the water by pump and motor.

Before storing the rainwater in tanks, a stilling basin in order to eliminate sand and soil particles should be prepared.

4 Utilizations of rainwater

- (1) Drinking water
- (2) Flush water
- (3) Fire preventing water
- (4) Gardening water
- (5) Water for factories
- (6) Upland crops
- (7) Cleanings for livings
- (8) Rainfed paddy rice field
- (9) Effective rainwater for paddy rice field
- (10) Separation of domestic pipe line between drinking and others in cities

5 Development of the storage techniques of rainwater

The development of the functions of apparatus and facility to store rainwater is very important. For example, the apparatus should be strong, low cost, compatible to local social needs, perfectly dark inside, and no dusts and soil particles, and good sanitary conditions. The followings are examples of the present rainwater storages.

- (1) Various cisterns
- (2) Various tank
- (3) Storage room underground of houses and buildings.
- (4) Ponds covered inside with impervious sheet (cheap cost)
- (5) Tameikes (small ponds)
- (5) Porous zone underground
- (6) Floating ponds on sea surface

6 Circulation system of rainwater stored

(1) Watering apparatus

(rainwater > tank > syphon spillway > filter > solar pump > drip irrigation systems > flowers and grass)

(2) Flush systems in the houses and buildings

(rainwater > tank > filter > pump > pipe line in buildings > flush apparatus > drains)

(3) Irrigation system for small farm

rainwater > reservoir > pump up > irrigation pipe systems > orchards and crops)

7 Pressured recharge pipes for rainwater to underground

Compulsive recharge of rainwater into percious ground of delta using the pressured water pipes with pump or static water pressure.

8 Rainfed agriculture in estuaries in Asia

We are producing much paddy rice on the wide area of the deltas in Asia. The utilization of effective rainwater for paddy rice field is very important. To realize this idea, integrated rainwater catchment systems for paddy rice field in the delta will play beneficial roles. Salinity control at some river mouths of the delta along the sea coast can be performed by various tide gates, one of them would be the "Floating Automatic Tide Gate(FATG)".

9 Rainwater catchment for remote islands

Integrated rainwater catchment systems as mentioned in this report should be adopted.

10 Lessons from the unusual dry spell at West Japan in 1994

1994 was seriously a dry year, of 100 years return period. All modern domestic water resources facilities which were planned and constructed through the modern standard of development (10 years return period:international standard) completely dried up. I will like to report on what counter measures were taken for this unusual occasion. Needs of integrated rainwater catchment systems was considered seriously.

- 1) Water utilization was regulated and decreased.
- 2) Old apparatuses and facilities of rainwater catchment system were searched and utilized actually. (recover of old wells etc.)
- 3) Rainwater catchment systems were seriously discussed.
- 4) Rainwater catchment systems were introduced in the big apartment in some big cities.

11 Lessons from the Great Earthquake Disaster at Hanshin Area of Japan in 1995

A great earthquake struck the Hanshin area which is the central part of Japan Island in January 1995. After the big disaster including collapsing of buildings and fires outbreak etc., we discovered that multipurpose water should be stored in many places of big cities, because most of the pipe line for domestic water would be destroyed by a big earthquake of 7 seismic grade on the Japanese scale.

This is a great lesson for the importance of development of multipurpose water storages in big cities to survive of a disaster occurs.

Integrated utilization of rainwater catchment systems would be considered as one of the counter measures against this.

Section 2

SOCIO-ECONOMIC CONCERN

**SOCIO-ECONOMIC ASPECTS OF RAINWATER CATCHMENT
SYSTEMS UTILIZATION: THE DEVELOPING WORLD PERSPECTIVE**

Datius G. Rutashobya*

INTRODUCTION

Lack of adequate water supply and sanitation facilities continues to be a source of serious problems in many countries all over the world. In the developing countries the water sources, on which the people rely for their needs, are often located far away from homes, and are usually contaminated or even polluted. This is more so in the rural areas. Rainwater catchment systems (RWCS) have proved to be effective both in urban and rural locations. Rainwater may supplement public water supply and, in some rural areas, may be the only alternative, especially where groundwater is unfit for human consumption.

Over the last fifteen years, increased attention has been directed towards water harvesting systems as a possible supplement or alternative to piped and pumped water supply in the developing countries. Significant attention has been addressed to rooftop harvesting in the Far Eastern countries. Unfortunately, there is less information available on such kind of practices in Africa, even though it is currently slowly gaining popularity.

When planning for a rainwater catchment project it is important to include the appraisal of the technical, social and economic feasibility of the proposed activities. If the project is community - based, as is true in most cases in developing countries, then a proper evaluation of community demands and institutional components is also very essential. Thus, a well planned rainwater catchment project has to take into account not only the "hardware" issues like low cost appropriate tank designs and construction techniques but also the "software" aspects, that are essentially socio-economic in nature.

In carrying out a cost-benefit analysis, rainwater catchment systems cannot only be viewed in terms of cost justification, but also in terms of such unquantifiable benefits such as time savings and improved hygiene.

There is always potential for social conflict arising from the development of water harvesting systems. Conflict may be over ownership, water allocation rights and inequitable abstraction. These problems are common in non-cohesive societies and under conditions of rising population (Lee and Visscher, 1992).

*Principal Hydrologist
Ministry of Water, Energy and Minerals
P.O. Box 35066 DAR ES SALAAM, Tanzania

COMMUNITY ACCEPTANCE AND WILLINGNESS TO PAY

The cost of rainwater catchment systems differ considerably from place to place within the same country, both in terms of capital cost and in the cost per unit volume of water supplied. This is due to the differences in labour costs, material costs and the number of rainy seasons.

In the developing world most water harvesting systems are communally owned. Before a central government, local government or other agency introduces a water harvesting system for community ownership it has to be ensured first that it will be accepted by the people. This is important because some rural communities have complicated attitudes towards new projects and services. There are many examples whereby seemingly good and profitable services, costing lots of money, have been rejected by their intended beneficiaries and have turned into 'white elephants'. The sustainability of community rainwater catchment systems requires that households contribute towards their construction. Willingness to pay for purchase of construction materials and tools is dependent on people's attitudes, as regards the potential benefits expected from the systems. Therefore, they have first to be accepted by the people.

Where aid is involved, the people may be reticent to mention some potentially conflicting obligations and responsibilities requiring their efforts and time (Skoda and Reynolds, 1994). The project may therefore be implemented, only to run into difficulties later. It is important therefore to make a thorough research first in order to ensure that the project is truly acceptable, and then establish its feasibility.

COMMUNITY AFFORDABILITY

Costs of water harvesting systems can be broken down into material costs, skilled and unskilled labour costs, supervision costs, and additional support costs. Most programmes do ask for contributions from end-users in the community in order to offset these costs. Most frequently, this is comprised of unskilled labour and the proportion of materials that can be obtained locally (Lee and Visscher, 1990). But sometimes the community is required to provide some financial contributions. If this turns out to be a necessary condition then it matters a lot whether the community can or cannot afford to contribute.

There are cases where the government is not able to provide rainwater catchment systems to the people. The people, instead, are motivated to build their own systems. Then it becomes a question of whether or not they can afford to build the systems. If there is no well developed mechanism for community financial

management then it becomes necessary to set up money-raising activities like communal fields from which financial contributions can be made. Alternatively, loans can be made available to those who want to construct their own household systems. However, financing repayment schemes must be made flexible and linked to socio-economic improvement and income generation to prevent the exclusion of the poorer groups in society.

SKILLS WITHIN THE COMMUNITY

It is always advantageous to have, within the community, people with skills for construction and maintenance of water harvesting systems. Hence, whenever it is found feasible to have RWCS as part of community water supply, plans should be made to train able-bodied men and women in order to equip them with the necessary skills. These people may then form special units or 'brigades' which would be called upon to construct both individual and community owned RWCS. Because these brigades will be within the communities the services rendered by them will generally be cheaper than if they were to be hired from outside the communities.

TECHNOLOGY CHOSEN

The construction of RWCS utilizes, as much as possible, locally available skills, materials and tools. It should follow then that there is need to take into account local cultural and socio-economic patterns in the selection of technologies for rainwater harvesting, as well as in the construction, operation and maintenance of the same (Gavidia, J., 1994). A conducive environment has to be created in order to encourage technological innovation as well as strengthening the capacity, within the community, for research and development of appropriate technological options in rainwater harvesting. Indigenous technologies should be the basis for advancement of RWCS, which should be applied in accordance to the available local circumstances of the area in question.

The choice of technology must match the community resources available, for the upkeep of the system. According to Wamani and Mbugua, 1994, various water projects in Kenya have employed borrowed water harvesting technologies, without reference to a study on the most appropriate technology for the community in question. This situation has caused those water projects not to attain the desired goals. This unfortunate problem is common in many developing countries in Africa, Asia and elsewhere.

COMMUNITY PARTICIPATION

Community participation in rainwater catchment systems is usually in the form of cash, provision of labour and locally available resources, decision-making in planning, implementation, system maintenance, etc. Hence, participation should not just be seen as community contribution in cash or labour. Planning and implementation of an activity which adopts water harvesting as a prime technology implies very close collaboration with the community and individual community members. The major focus needs to be on capacity building to ensure that efficient use is being made of the harvesting facilities, and that adequate upkeep and future expansion can be carried out largely by the community itself.

Lack of community participation in project planning and implementation has rendered many projects unsustainable. On the other hand, Gould 1991, relates the rapid expansion, worldwide, in the use of rainwater catchment systems technology to the growing interest in the community-based, self-help development programmes. Water harvesting systems demand a high and sustainable level of community involvement in management. This requires a corresponding level of commitment by the community concerned. The agency responsible for construction of RWCS has to make it easier for the community members to participate and should also help them to organize themselves in order that as many people as possible may participate in decision making at the various phases of project implementation. In this regard, the establishment of partnerships between the public sector, NGOs and community organizations is a requisite to make efficient use of all the capacities available at the local level (Gavidia, 1994). It should be borne in mind that the most suitable water supply system is that developed with the involvement of the local people, thus creating a sense of responsibility and ownership within the community.

SERVICE LEVEL PROVIDED

A common feature among developing countries is that there is always limited resources to satisfy the needs fully. With regard to rainwater utilization it is usually not easy to provide sufficient amounts for all the people. What service level to be provided with the available resources, becomes the question then. The obvious solution, and usually what is done, is to provide a partial improvement of local conditions by providing a better

water supply for part of the year. Water scarcity problems normally becomes more serious during the the dry part of the year. This is the time when RWCS should play a more significant role in mitigating water shortage problems. Rainwater cisterns should be full at the end of the rainy season, to be used for part of, or the whole of, the dry period, depending on the cistern capacity and per capita water consumption.

It can be said then that the service level provided by RWCS depends on the available resources, which determine the capacity of storage tanks, assuming sufficient rainfall is available to fill up the tanks.

SYSTEMS OWNERSHIP

Whether a community RWCS has been constructed through resources provided by the government or external agency or by the community itself it is of utmost importance that ownership of the system be vested in the people who benefit from using it. A feeling of ownership carries great weight for the good and survival of the system. The community will feel responsible for the system when they know it belongs to them. They will then care for it, ensure its proper maintenance as well as its security. There are unfortunate examples of cases where a water supply scheme for community use is 'vandalised' by the end-users themselves. Close scrutiny of such unexpected incidents often reveals that the 'vandals' don't feel that the systems belong to them. This happens when the community members were not made to participate in the various stages of implementation of the project.

It is important therefore that after construction of a RWCS the beneficiaries must take full responsibility for its operation and maintenance. They should carry out any necessary repairs to the systems themselves and any relevant costs should be met from within their contributions. Technical or financial assistance may be sought only when it cannot come from within the community members.

SOCIAL CONFLICTS

When large RWCS are introduced, it becomes necessary to have a high level of community organization. The organized division of water amongst users and its sensible use through a dry period is necessary to ensure that equal benefits are received by all (Lee and Visscher, 1990). In some instances it may be necessary that

water is used only for drinking, cooking and washing, in order that it may be enough to run through the dry spell. If these limitations are not observed social conflicts may arise out of unequal abstraction of stored water. Water use discipline becomes essential.

Another type of conflict may be between the users of the RWCS and the owner of the site where the system is located. It happens sometimes that due to unavoidable reasons, a community system has to be constructed in a premise that is privately owned by an individual or organization. If access to the premise is restricted by the owner, it could be a cause for social conflict. Conflicts over ownership of the system may arise, as well, amongst the community members themselves, when community leaders feel they own the system and have more right than the ordinary members.

SYSTEMS MAINTENANCE

As mentioned already, most RWCS, except for individual roof catchments, are communal systems, and require organization of the community to manage and maintain them. A successful community water supply programme involves a combination of hardware and software technology, and institutional and organizational support elements, matched in such a way that the people to benefit from the improved supply can afford the cost of operating and maintaining it, and have the skills, spare parts, materials and tools available to make it sustainable (Wamani and Mbugua, 1994). The users must, therefore, have funds from which maintenance costs may be met.

Experience in the third world countries shows that many expensive and well constructed water supply projects have operated for only a short time due to lack of proper maintenance. Lately, the importance of maintenance has been accorded significant weight, by entrusting this activity to the end-users, and this has helped quite a lot in prolonging the life span of water projects and schemes. Likewise RWCS should be maintained regularly, as required. When the system is used by the whole village or large community group as a common resource the responsibility of maintaining the system will be delegated to specific members who will do the work on behalf of the rest of the village or community.

LONG-TERM SUSTAINABILITY

RWCS do not generally suffice for all water needs. But due to population increases there is a possibility of not meeting, even the needs that are normally satisfied through rainwater harvesting. This is because the finite supply from harvesting systems must be split between larger numbers of people. Hence, systems have to be expanded with time in order to achieve long-term sustainability. This is possible if there are income generating means, necessary for financing the expansion. Communal farms, shops and other small enterprises may be useful in generating such income. Arrangements may also be made to acquire loans from savings and credit institutions and repayments made slowly. What is important is to organize a permanent financial structure and methods for re-investment.

Training local community members in construction and maintenance of the systems is essential for sustainability. The trained individuals will be the ones to ensure continuous utilization of the systems. As will be discussed below, sustainability largely depend on women in the community.

ROLE OF WOMEN

Water is of particular importance to women, especially rural women, since they are the main providers of water for domestic use. This is particularly true in Africa. There is need to focus on women as prime targets for water harvesting system development through their involvement in all project activities.

Technical experts have persistently failed to consider the needs of women as relevant issues in implementing water harvesting systems. The inclusion of women should entail their involvement in the actual planning, construction and maintenance of the system, as well as financial aspects. Table 1 below shows a number of special steps which may be necessary to involve women next to the men who are often participating more automatically.

Table 1: Ten main steps for including women in the full project cycle

- . Orient male project managers to the benefits which involving women has on the achievement of project objectives.
 - . Work with women field agents.
 - . Discuss with local leaders the need to involve women in planning and development.
 - . Make sure women are informed about meetings and that they participate.
 - . Organize meetings when and where women are able to attend.
 - . Organize women participants to sit together at meetings, in a prominent location and to speak out.
 - . Stimulate discussion by actively inviting criticisms from women and asking respected women to speak.
 - . Organize special meetings to involve the poorest women so that their views are heard.
 - . Decide which management roles are best carried out by women and explain the requirements to candidates.
 - . Adapt skills training to women's needs and provide follow-up support and monitoring of progress.
-

Source: van Wijk, 1989

SUMMARY AND CONCLUSIONS

In the utilization of rainwater catchment systems, in the developing countries, there are a number of important socio-economic aspects that have to be satisfied. First, the community members have to accept the RWCS technology and should be willing to pay for their construction and maintenance. Then, they have to be in a position to afford them. There should be skilled people within the community to construct and manage those systems. The technology chosen has to suit the available local conditions. Community participation is important and the women have to play a big role. The systems must be owned by the users themselves and must be properly maintained. It is also important to ensure long-term sustainability of the systems.

It may be concluded that socio-economic aspects have to be carefully observed and satisfied in order to have successful utilization of rainwater catchment systems in the third world.

- Gavidia, J., 1994. "Overview: Socio-economic Aspects," in proceedings of the sixth International Conference on Rainwater Catchment Systems, Nairobi, Kenya, Edited by G.K. Bambrah, F.O. Otieno & D.B. Thomas.
- Gould, J.E., 1991. "The contribution of Rainwater Catchment Systems to the International Drinking Water Supply and Sanitation Decade; Lessons from Thailand," in Proceedings of the Fifth International Conference on Rain Water Cistern Systems, Keelung, Taiwan.
- Lee, M.D. and Visscher, J.T., 1990. "Water Harvesting in Five African Countries". Occasional Paper 14. IRC International Water and Sanitation Centre, The Hague, The Netherlands.
- Lee, M.D. and Visscher, J.T., 1992. "Water Harvesting: A Guide for Planners and Project Managers". Technical Paper Series No. 30. IRC International Water and Sanitation Centre, The Hague, The Netherlands.
- Skoda, J.D. and Reynolds, C., 1994. "Rainwater Catchment Systems in South Pacific Islands: Experience of Project Implementation", in proceedings of the sixth International Conference on Rainwater Catchment Systems, Nairobi, Kenya. Edited by G.K. Bambrah, F.O. Otieno & D.B. Thomas.
- Wamani, W.T. and Mbugua, J.K., 1994. "Rainwater Harvesting in Kenya: State of the Art and Related Socio-economic Issues", in Proceedings of the Sixth International Conference on Rainwater Catchment Systems, Nairobi, Kenya.
- Wijk-Sijbesma, Christine van, 1989. "Community management and sustainable water supply in developing countries." paper presented at the Dutch Water Sector Day, 8 December 1989. The Hague, The Netherlands, IRC International Water and Sanitation Centre: Quoted from Lee, M.D. and Visscher, J.T., 1992.

Flood Migration And Water Harvesting : Benefits from Rainwater Utilization

Luo, Ching-Ruey*¹

Ju, Yih-Zen*²

ABSTRACT

Due to the increasing of Water demand with the decreasing of conservative water resources, "how to effectively utilize the conservative water resources and how to have new or supplementary water resources" becomes very important and essentially necessary. Rainwater usually is caught by reservoir at upstream, which also creates some environmental, economical and social impacts. When rainwater drops at middle stream or downstream, we always let it flow down into sea. Rainwater-a best blessed gift, of course, will sometimes result in flood, but it also can give us some benefits. In this paper, an example will tell us how to reduce the damage from flood and to get the benefit from the rainwater catchment system. The economic efficiency, benefit-cost ratio, before and after Rainwater Cistern-Supply System (RWCS) constructed, will also be discussed.

INTRODUCTION

The Tou-Chang river, one of the main river in Taiwan, combining with two branches called San-Pin river and You-Luo river at upstream, has 63.03 km long, catchment area 565.94 km² and mean slope 1/190. The Hsinchu Science Park and Industrial Technology Research Institute, area 900 hectares, are located at the middle

*1 Doctor of Engineering, Researcher of ITRI

*2 Associate Researcher of ITRI

stream of the Tou-Chang river basin. Because this industrial estate is quite important for high technique development of Taiwan, the drainage problem in this estate becomes obviously sensitive. The following paragraphs will show us the drainage planning (flood control), the Rainwater Cistern-Supply System (RWCS) function, and the benefit-cost ratio before and after RWCS constructions.

FLOOD ROUTING AND ANALYSIS

In order to have the flood-control planning for drainage, the following steps are made :

A. Mean Dimensionless Curve (MDC)⁽¹⁾

The MDC is obtained by utilizing the flood-time discharge associated with the simultaneous mean rainfall of the Tou-Chang river catchment. the MDC is shown in Figure 1.

B. Unit Hydrograph of Discharge (UHD)

The UHD is formed from MDC in Figure 1. The time lag is 3.56^{hrs} and unit time 1^{hr}, and $t_s = 4.06^{\text{hrs}}$ the UHD is presented in Figure 2.

C. Maximum 48^{hrs} Stormy Rainfall Analysis⁽¹⁾

From the annual maximum 48^{hrs} rainfall data of the Tou-Chang river, the flood-frequency analysis of stormy rainfall at Er-Churng Station is as following in Table 1 :

T(yr)	200	100	50	20	10	5	2	1.11
P(mm)	1,103	914	748	559	436	326	193	95

The infiltration is 4.56mm/hr vs. 10mm/hr exceed rain

D.Flood-Frequency Curve of Discharge

By combining the results from Figure 2 and the above stormy rainfall analysis, the frequency analysis for different return period, T, of the drainage is in Table 2 :

Table 2 Flood-Frequency Analysis

T(yr)	200	100	50	20	10	5	2	1.11
Q(cms)	529	439	359	268	208	156	93	46

E.Flood-Damage with Flood-Frequency (FD-FF)

Based on the return period, T, equal to 20^{yr} , the annual cost, including constructing drainage, operation and maintenance, is U.S. \$ 1,961,000 ; while the annual benefit directly and indirectly from the drainage planning, such as high level utilization of land and more job chances, etc., is U.S. \$ 1,886,000. The B/C ratio is 0.96. In order to compare the difference before and after the flood-migration, the damage without constructing drainage with different return period is plotted in Figure 3, and it is called FD-FF relationship.

RAINWATER CISTERN-SUPPLY SYSTEM (RWCS)

A flood-migration used to separate the flood and delay the flood peak is to store 60c.m.s. stormy rain for 1 hour, that is to reduce the flood peak from $T=20^{yr}$ to $T=10^{yr}$, corresponding to reduce rainfall $p=123\text{mm/hr}$, The needed area is obtained by,

$$Q = C \cdot I \cdot A$$

$$60^{\text{cms}} = 0.8 \times 123 \text{ mm/hr} \times A$$

$$\therefore A = 2,195,200 \text{ m}^2$$

The storage volume :

$$= Q \cdot t = 60^{\text{c.m.s}} \times 1 \times 3600^{\text{s}} = 216,000 \text{ m}^3$$

From the results of constructing RWCS⁽²⁾, the mean annual benefit is 0.33 U.S.\$/Ton, while the mean annual cost is 1.20 U.S.\$/Ton.

From the FD-FF, the reduced discharge from 268^{cms} to 208^{cms} due to storing 60^{cms} for 1^{hr}, that is the return period changed from 20^{yrs} to 10^{yrs}, in Table 1, the damage reduces. This is the benefit from the flood migration.

Now, the total benefit after flood-migration is :

$$1,886,000 + 1,154,000 = \text{U. S. \$ } 3,040,000$$

and the total cost after flood-migration is U. S. \$ 1,961,000

Finally, the B/C value after flood-migration without including RWCS effect is

$$\frac{3,040,000}{1,961,000} = 1.55$$

If we count the effect of RWCS, the total benofit will become

$$1,886,000 + 1,154,000 + 1,494 \times \frac{2,195,200}{375} \times 0.33 \approx 5,926,100 \text{ U. S. \$}$$

and the total cost will be

$$1,961,000 + 216,000 \times 1.2 = 2,220,200 \text{ U. S. \$}$$

Then, the benefit-cost ratio is,

$$B/C \approx 2.67$$

CONCLUSIONS

RWCS is used not only for storing the ordinary rainwater but also for the stormy rainfall. In the industrial estates, so many roofs of building can be used as the function of RWCS. The ordinary rainwater is caught for utilizing as the miscellaneous water, while the stormy rainwater is caught for avoiding the suffer from flood. This is a good example of high efficiency for utilization of rainwater.

ACKNOWLEDGEMENTS

So many colleagues do this work with me. Mr. Lin, T.Y for word processing arrangement ; Mr. Yu, S.Y for drawing picture ; and Ms. Hwang, H. M. for typing. Here, I want to show my deeply-minded thanks for their helps.

REFERENCES

- 1.Taiwan Provincial Water Conservancy Bureau, "Regulation Report of the Tou-Chang River", 1984.
- 2.Luo, Ching-Ruey., "The Vanguard Research of Rainwater Cistern-Supply System in the Industrial Area of Taiwan", 7th International Conference of the International Rainwater Catchment System Association, Beijing P.R. China, June 19-25, 1995.

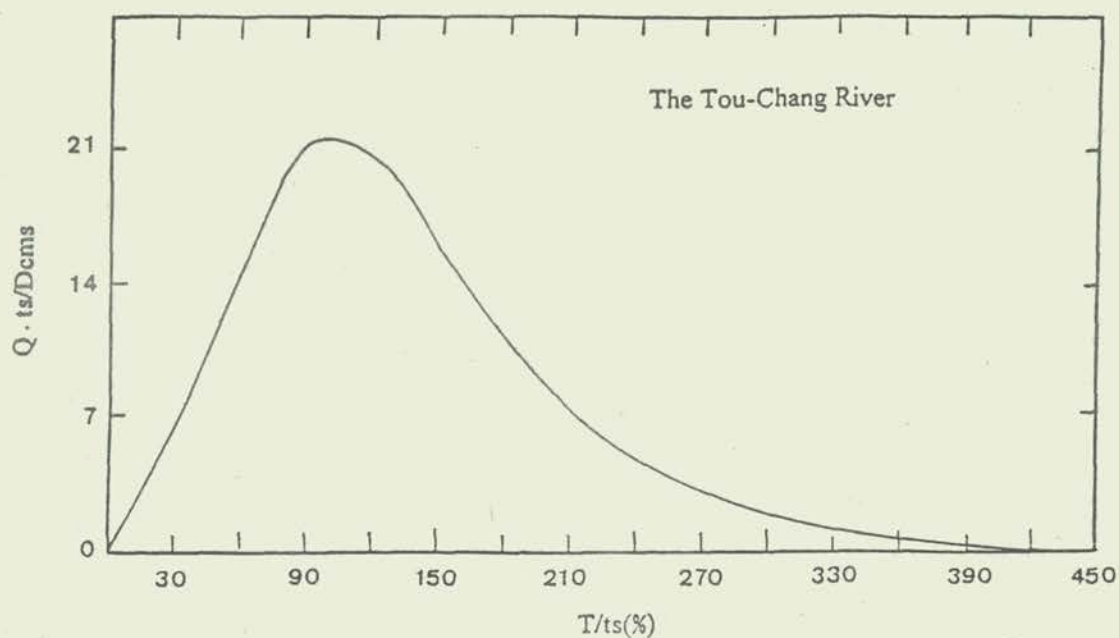


Fig.1 Mean Dimensionless Curve

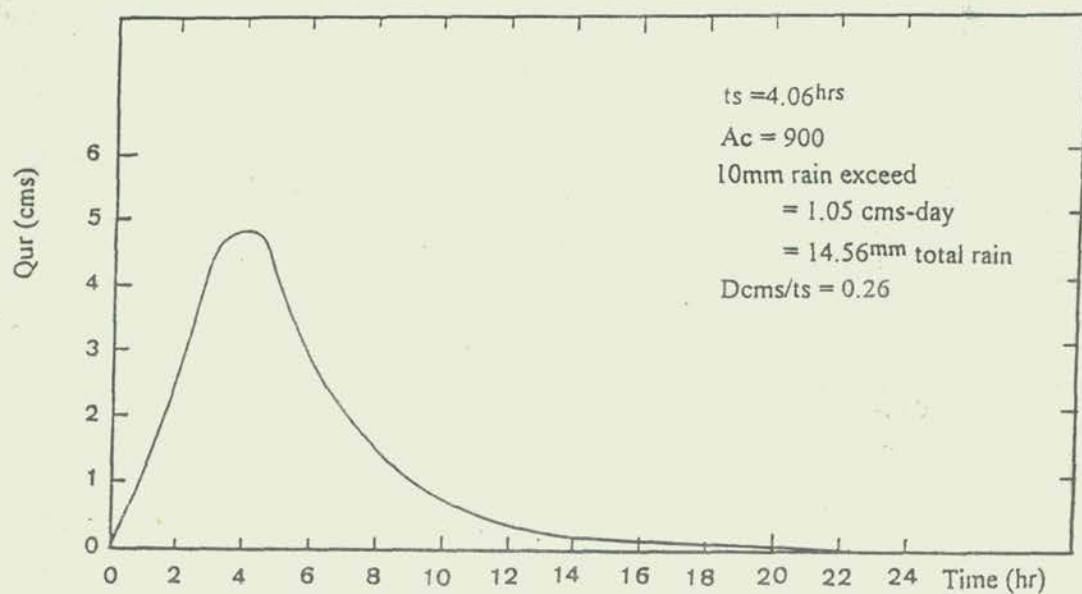


Fig.2 Unit Hydrograph of Er-Churmg Station

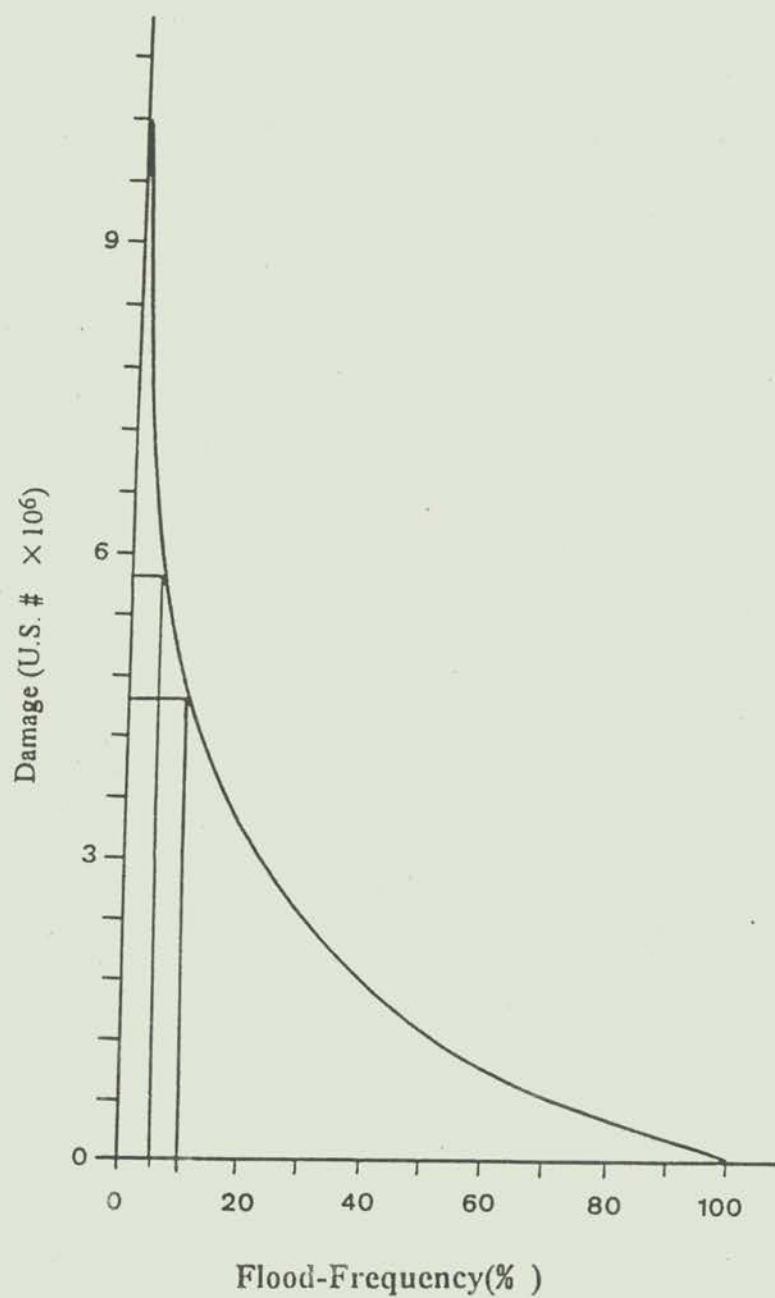


Fig.3 The FD-FF Curve

INDIGENOUS RAINWATER HARVESTING SYSTEMS IN SRI LANKA : CURRENT STATUS AND AN ECO-SYSTEM APPROACH TO REVITALIZATION¹

C.M. Wijayarathna² and A.S. Widanapathirana³

ABSTRACT

Rainwater harvesting for agricultural and rural development has been practiced in Sri Lanka since the pre-Christian era. The evidence indicates that as far back as in the 450 B.C. series of small tanks have been constructed to store water during the period of its abundance so that it could be used during the water deficit periods. These tanks had been constructed in such a way to join one another from upstream to downstream so that the maximum utilization of rainwater is ensured. This arrangement is described as small tank cascade system. This tank eco-system is such that the reservoir is located in the lower landscape while the area above is covered by forest, the latter serving as the catchment. On either side of the reservoir are the homesteads and further away from the catchment and homesteads is the area which is used for *chena* or shifting cultivation. Just below the dam is command area where mainly paddy and rarely other food crops are cultivated under irrigation. In ancient times the entire agricultural systems had been governed according to a set of established norms aimed at optimum utilization of land and water resources. A tank itself has several features in order to reduce siltation, lengthen the storage life of water and a system of natural purification of water. In addition to agricultural production benefits, the small tank cascade systems offer several other benefits such as fish, flood control, maintenance of water table, lengthening the period of water availability, soil conservation and reduction of siltation. The small tank cascade technology and the institutional landscape surrounding them have been time-tested for its adaptation to the local environment.

Evidence indicated that the small tank cascade system had functioned satisfactorily until the 12th century A.D. Thereafter, the system started to decline due to several reasons, and a large number of them were completely abandoned. During this long period of abandoning, some tanks were breached, siltation became serious and the people even left some of the tank eco-system. Several of such breached tanks have been restored subsequently. However, at present, only some of the tanks belonging to the pre-Christian era is in operation. The present status characterizes low and variable cropping intensity, low harvest ratios and crop yields, and deforestation in the catchments. Social problems are considered to be serious and resource degradation and depletion have appeared to be intense. The institutional system has subjected to a series of changes and the orderly manner within which tank resources were managed in the past are no longer a reality.

¹ A paper presented at the 7th International Rainwater Catchment System Conference, June 19-25, 1995, Beijing, China.

² Head, Sri Lanka Country Program, International Irrigation Management Institute, IIMI.

³ Socio-Economist, Participatory Forestry Project, Sri Lanka Forest Department.

A series of small tank cascade systems has been selected for a program of action research by the Project titled "Shared Control of Natural Resources (SCOR)" in 1993. The Project is experimenting with various models for the optimum management of tank resources and a desirable institutional strategy. Among the innovations being tested under SCOR Project are: (a) revitalization of tank eco-system, (b) strategies to increase the yields and cropping intensity on a sustainable basis (c) experimenting with a suitable system of landuse for the entire eco-system and (d) evolving an institutional system to manage the resources. The work under SCOR is in progress and the concepts, strategies as well as achievements and constraints to date are discussed in the paper.

INTRODUCTION

"Two different systems were adopted in Ceylon⁴ for conserving the abundance of water dispersed over the plains during the seasonal rains of the monsoons. According to one, the natural and effective plan of making use of the upper reaches of a valley and embarking its outlets was resorted to. The other system was based much more scientific and ambitious methods, and aimed at securing a greater volume of water than any local catchment area could have supplied. This was effected by constructing massive causeways and anicuts across the larger rivers and turning the water into excavated channels which conveyed it sometimes many miles, over apparently flat country and impounded the water eventually in large reservoirs or a chain of small reservoirs.

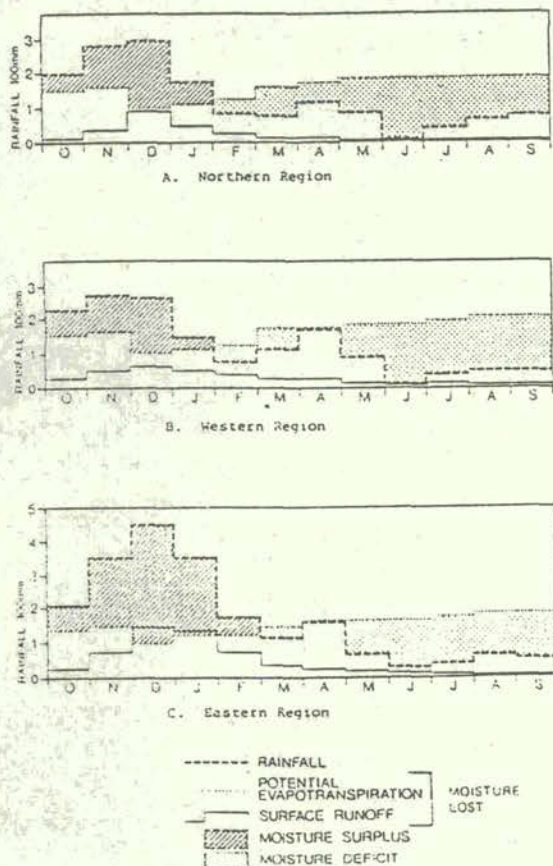
So careful were the inhabitants in husbanding the liquid resources on which their very existence depended, that even the surplus waters from one tank which could spill when water was plentiful, were not allowed to escape. The tanks were built in orderly method at slightly varying elevations so that there often was a series of reservoirs to take the over flow from the one above it. The exit of water was regulated by means of sluices to the rice fields. In this manner, the face of the country came to be thickly dotted with these reservoirs and the aspect of the intervening spaces heightened by cultivation"

- Brohier, 1934: P.2. -

As Brohier commented, Sri Lanka had a strong tradition of tank irrigation using an elaborate network of channels, and the historic evidence shows that, from about the 5th century to 15th, irrigation activities played a crucial role in sustaining ancient empires. "The ruins of the irrigation works show the extent of the Island's prosperity in this sphere of activity. the first Aryan settlers of the Island realized the need for a system which did not depend too heavily on the uncertainties of the seasonal rainfall" (Dikshit, 1986 pp.126, 127).

⁴ Sri Lanka was named "Ceylon" before 1972.

Sri Lanka is divided into two major climatological regions, namely, dry zone and wet zone: the rainfall isoquant of 1900 mm/annum is the boundary between them. The dry zone receives a highly variable basically bimodal rainfall distribution⁵. Nearly 75 percent of rainfall comes in the wet season. Even in this case the distribution is not uniform and can be erratic. In the North-Central dryzone of Sri Lanka, the surplus water condition during October-January is followed by a long dry spell which is only interrupted briefly during March-April. "April rain may be low in one year, may fail altogether in another year and yet another year may be high but short lived and very intensive. Moisture deficit is at its highest during May-September period due to extremely low rainfall, dry winds that dry the surface and very high temperature in the windiest period, June-August" (Tennakoon, 1986 p. 62).



Source: UNDP/FAD and Government of Ceylon: Mahaweli Ganga Irrigation and Hydropower Survey-Ceylon. Final Report Vol. 1 (Rome 1961)
Reproduced from Tennakoon 1986

Figure 1. Moisture Surplus and Deficit in the North Central Dry Zone of Sri Lanka

Moisture surplus and deficit in North Central dry zone is illustrated in Figure 1. In general, success of dry season crop depends largely on the availability of irrigation. This "risk minimization process of water regulation (tank construction) and inundated paddy cultivation which is the basis of subsistence economy in the dryzone, has evolved in conformity with the topography and drainage pattern in the region". (Tennakoon, 1986 p.72)

An analysis of the rainfall pattern, natural drainage system and the distribution of tanks in the dry zone areas of Sri Lanka, especially in the Anuradhapura district where tank-based irrigated agricultural production systems had evolved in ancient times would lead one to consider it as a rain-water harvesting system (Figure 2). In response to climatic problems, notably the undesirable distribution of rainfall, Sri Lankans in ancient times have been experimenting with various techniques to collect and store water, essentially run-off during the wet season for use during the

⁵ Consequently, two district crop seasons, namely *maha* (wet) and *yala* (dry) are identified.

DISTRIBUTION OF MAJOR & MINOR RESERVOIRS/TANKS
IN THE
ANURADHAPURA DISTRICT
SRI LANKA

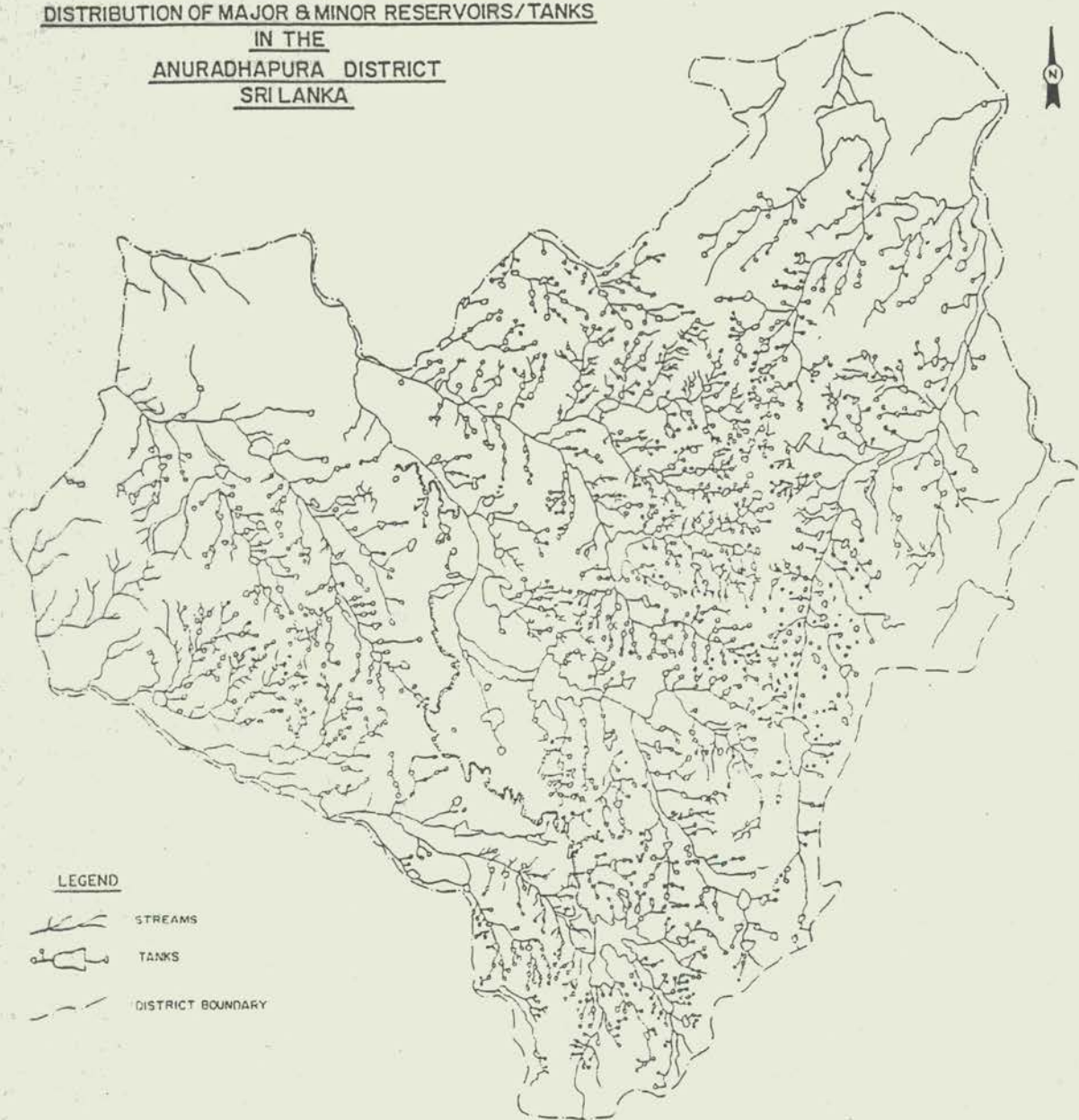


Figure 2

dry months. The main method of collecting was to construct large storage devices, tanks, by damming a natural depression. Through active experimentation, the Sri Lankans have devised various hydraulic structures to release the water stored in the tank for cultivation of the fields below by gravity irrigation. These ancient irrigation models for capturing, storage and utilization of run-off date back to the fifth century BC. Some of the tanks constructed during the pre-Christian era are in use even today.

As knowledge of irrigation expanded, the early settlers built small-scale reservoirs in the villages they occupied for agricultural production and domestic needs. They learnt through continuous experimentation and testing to advance from village tank to major reservoirs during the period 65-109 AD. This is a remarkable achievement in the history of irrigation in Sri Lanka (Widanapathirana, 1992, p.5). The king who had contributed the most to the development of tank irrigation systems has started "..... in a country such as this not even a drop of water that is obtained by rain should be allowed to flow into the sea without benefitting man" (King Parakramabahu the Great, 1153-1186 A.D., Mahavamsa, Part II, quoted in Farmer 1967).

Poor distribution of the rainfall, and not its insufficient amount, is the main factor explaining poor performance of rainfed farming. Hence, the principles of water harvesting in ancient systems in Sri Lanka included the construction of series of storage structures on the basis of landscape & natural drainage characteristics of river basins/watersheds and techniques to make use of stored water for crop production.⁶

A recent study by the International Irrigation Management Institute revealed that, in the small valleys of the undulating dry zone terrain, less rapidly moving water cascades from the crests of the low ridges to the keels of the small valleys are intercepted with man-made small and narrow earth bunds of low elevation, to create tanks, big and small. The small tanks are constructed in the upper slopes of the small valleys and the bigger ones are constructed in the keels of the valleys. Furthermore, it is to be noted that the tanks in a keel usually become bigger and bigger as one moves downstream a valley. Water in these reservoirs in a valley, cascades from one to another, starting from upstream towards downstream into a considerably large reservoir far below and finally the volume of water spilled over from that large reservoir at the far end enters a large stream.

One of the cardinal strategies adopted in tank construction in a cascading valley seems to be the strict adherence to:

- (a) have an adequate volume of water in every tank of the settled villages in a cascading valley even in a year of below average rainfall;
- (b) institute a regulated flow of water from one tank to another downstream, avoiding sudden influx of large volumes of water in order to minimize the risk of tank bund breaching; and
- (c) have some reservoirs in reserve in the head-end portions of the valley to meet irrigation shortfall of the main village fields as well as water holes for wild animals and village cattle.

In tank cascades, bunds of upstream tanks were never allowed to be raised to impound more water than originally intended to. An ad-hoc bund raising has two negative consequences -- submerging tail-end fields of the immediate upstream village and the denial of some water to the tank downstream of it, causing irrigation water shortages. Thus, spill

⁶ As Brohier stated: "What an unspeakable blessing that against such calamities a security have been found by the introduction of a grain calculated to germinate under water" (Brohier 1934, p.2)

level, diameters of irrigation sluices, as well as the levels of their placement (sill levels), bund top levels, release of water per field irrigation were all done having in mind the entire network of tanks in a cascading valley. In addition, the hydraulic inter-connection of groundwater flow from one tank to another and irrigation return flow from upstream command to downstream tanks make it more important that the tanks in cascade be studied holistically to identify their hydrologic inter-connectors. (Sakthivadivel et.al., 1995)

A minor tank cascade system is a sub-system within a (river) basin watershed. (frequently used in this paper as watershed). The term watershed is defined as the area of land surface that drains water into a common point along a stream or river. The rationale for using the river basin watershed as the basic unit for integrated planning of (land and water) resources utilization is clear. The watershed is a physical entity geographically defined by an important natural resource, water; the ways in which the water in the upper parts of the watershed are used affect the ways in which it can be used downstream, and they affect the associated land resource. Thus, the various parts of the watershed are physically and operationally linked in important ways, and the potential benefits from integrated use can be large.

To develop and maintain a balance between production and protection (or conservation) an on-going action-research project - namely Shared Control of Natural Resources (SCOR) has focused on watersheds as the basic planning, co-ordinating and implementation units. The project is being implemented by the International Irrigation Management Institute (IIMI), and the Government of Sri Lanka and is funded by the United States Agency for International Development (USAID). SCOR has selected two watersheds representing different agro-climatological and hydrological characteristics, each from the wet and dry zones of Sri Lanka. The dry zone pilot watershed, namely Huruluwewa (Figure 3) is located in the Anuradhapura district (shown in Figure 2). There are about 220 minor tanks and one major tank in the Huruluwewa watershed. In addition, ground water extraction from the weathered rock upto a depth of about 10m is taking place in an increasing rate. (Figure 4)

In the initial phase of SCOR implementation, several tank cascade systems or sub-watersheds within the Huruluwewa watershed have been selected for pilot research interventions. Prior to participatory planning aimed at revitalization of deteriorated tank ecosystems, SCOR examined the past and present land use patterns of various segments in a typical watershed.

Tennakoon (1974) has identified five "broad zones" in a typical traditional tank - village system (Figure 5). Zone 1 is the tank which could be considered as the "nerve centre" of the village economy. The geometry and hydrology of the tank is important as it determines the size of the area that can be irrigated and the cropping intensify. Zone 2 is the **Purana wela** (old field), which is located much closer to both the settlement and the tank.

In traditional systems, the land in this zone, which can be irrigated even if the water level is fairly low, has been divided between all the villagers. On the contrary, the land in zone 3, which are owned by few individuals, is usually irrigated by a higher level sluice. Even in instances where the tank is operated by a single sluice, the irrigation supply can be less satisfactory due to its distance from the tank (Tennakoon, 1986). Traditionally zones 1 and 2 have been cultivated to paddy (rice). "Paddy cultivation is the whole basis of village life with institutions, customs, beliefs and values rooted in it. Secondly, under normal weather conditions the farmer always gives first priority to paddy cultivation which has its implications on highland and **chena** (slash and burn) cultivation. Thirdly, the social value attached to the ownership of paddy land, especially the 'old field', is still strong. One's place in the village rituals and festivals, role in community work, chances of becoming a leader and at one time

DISTRIBUTION OF WATER RESERVOIRS AND AGRO-WELLS IN HURULUWUWIA WATERSHED



Figure 3

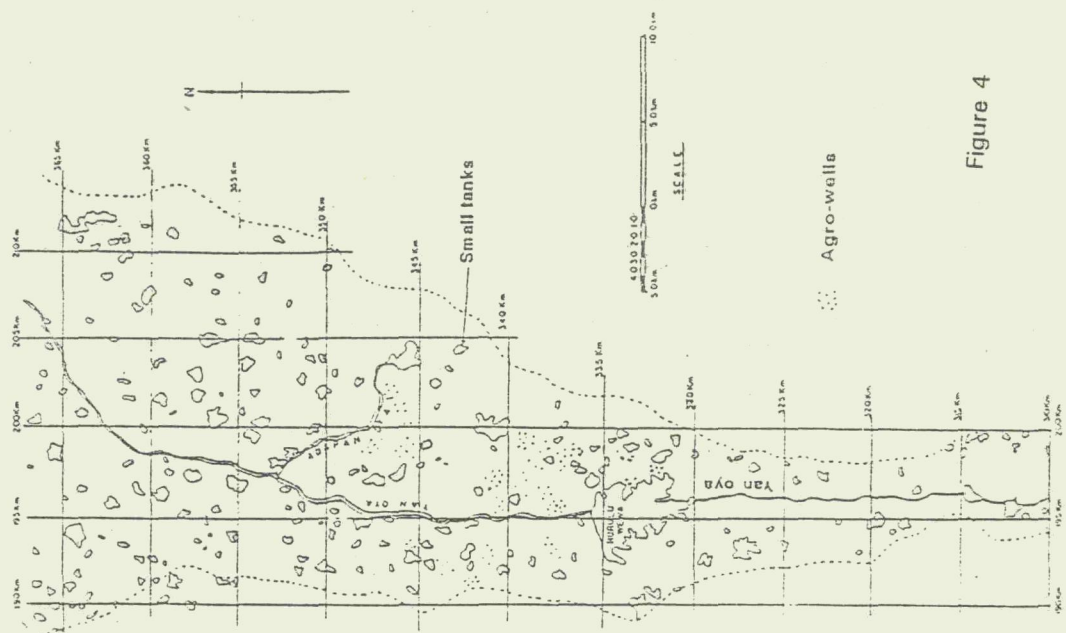


Figure 4

even the right to fish in the tank were restricted to persons with some claim to 'old field'. However, in recent years this trend is fast disappearing particularly with the presentation of the market economy" (Gooneratna et. al., 1980, p. 68).

Irrigation is nearly impossible in zone 4; mainly because of the distance and, in general, is covered short grasses, isolated trees and bushes. Zone 5 covers the largest extent of "village land" (Tennakoon, 1986). This zone is usually called the village/community forest. However, mainly due to shifting or slash and burn cultivation and illegal logging activities scrub lands have increased at the cost of forest. In the wet season Chena⁷, coinciding with the main rainy season, a variety of non-rice crops - such as grain, millets, pulses - is cultivated. Dry season chena is not common and involves cultivation of crops such as gingerly.

The home gardens are generally planted with perennial crops. In general in the study area the cropping intensity (70%-80%) and land productivity (2000-3000 kg/ha) are low in the paddy fields and large extents of under-utilized highlands, both state and privately owned (including home gardens), formed a common feature in the pre-project land use pattern.

SCHEMATIC DIAGRAM OF A TYPICAL DRY ZONE VILLAGE

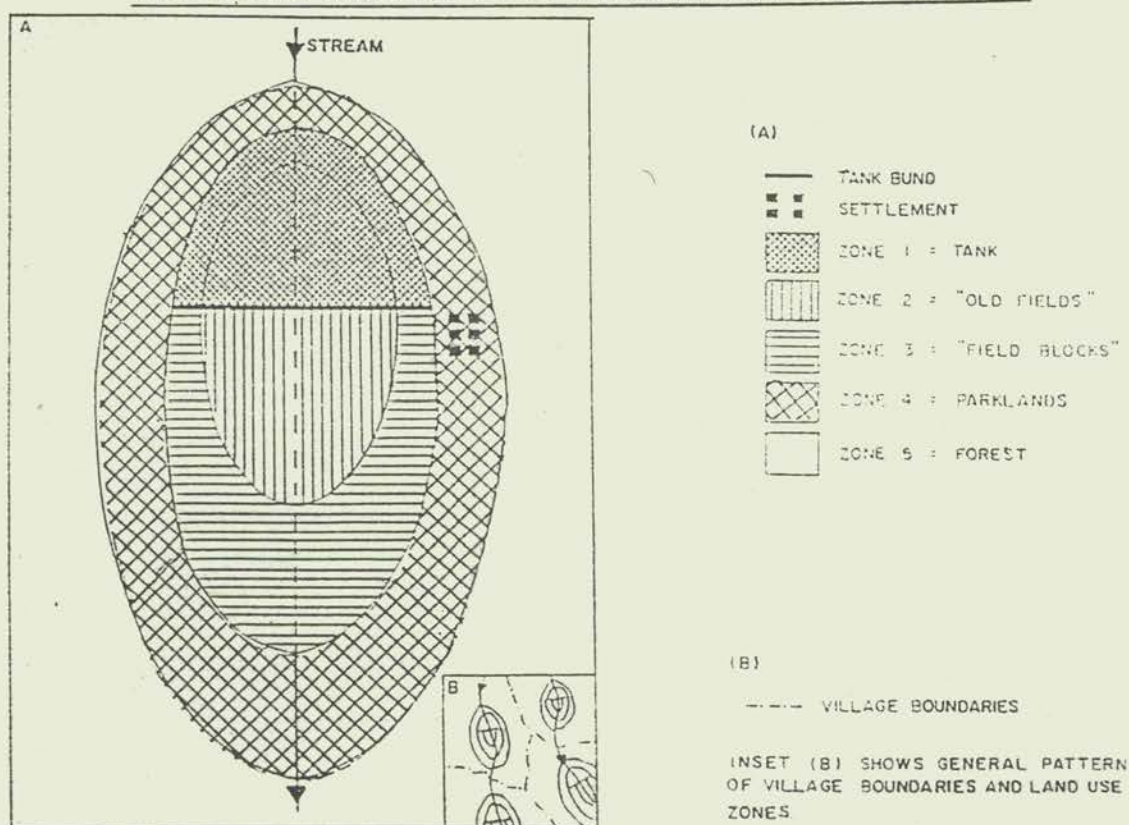


Figure 5

⁷Slash and burn cultivation

The SCOR approach emphasizes the need for an integrated ecosystems approach to dry zone development, considering the hydrological, socio-economic and other interventions between the various segments such as catchment, tank, command and drainage areas and associated highlands.

Participatory Development of Tank Ecosystems - Integration of Conservation Concerns with Production Goals

The selected sub-watersheds or tank cascade systems for SCOR action-research are contiguous areas of manageable size, having characteristic profiles of ecological, socio-economic and environmental features similar to that of the respective main watersheds. Size of these selected pilot sub-watersheds ranges from about 200-1000 ha. One such sub-watershed/tank cascade system is being used in this paper to illustrate the SCOR participatory action research process aimed at the development of tank ecosystems. This hydrological characteristics of this sub-watershed, namely Maha Meegaswewa (MM), is shown in Figure 6. Action is being taken through a participatory process to learn, test and demonstrate on "ideal" land use pattern with due emphasis on production and protection. This participatory approach of developing methodologies for combining technology, organizations and resources would illustrate the various production-protection elements with their intimate relationships, that will have to be incorporated in the management of watersheds or tank ecosystems in a sustainable manner. Micro concentration on contiguous areas or tank ecosystems within which "every inch of surface" is carefully planned and monitored for the impacts of participatory research intervention is a unique characteristic of SCOR.

Participatory Appraisal of Tank ecosystems

In the selected sub-watersheds, participatory appraisal of the characteristics of resource uses and users as well as mapping of current resource use were done by groups comprising of resource users/farmers, local officials of government agencies such as Irrigation, Agriculture, Forestry and Agrarian Services departments, IIMI-SCOR professionals and catalysts. The catalysts took the lead role in preparing the resource use maps and recording information. General objectives of this Participatory Rapid Appraisals were to:

- a) Prepare a detailed map of the tank ecosystems indicating: the land use pattern of individual holdings in the entire tank (cascade) ecosystem/sub-watershed (catchments, command areas, homesteads, drainage areas etc.), cropping/vegetation patterns, type and quality of cropping/vegetation cover, tank and the natural drainage system, road network, residential pattern.
- (b) Develop a database, including basic data such as: type and membership of user organizations, land fragmentation, ownership and tenurial patterns, cropping patterns and intensities (current and in the recent past), slope category, apparent degree of soil erosion, conservation practices, cultivation practices, input use for agriculture, production and productivity, and constraints to production and protection, yield performance, profits derived from different holdings in different zones. Social organizations including farmers organizations, conflicts, assistance from government support services and NGOs.
- (c) Help establish a baseline for the resource use pattern using (a) and (b).
- (d) Sensitize the officials of relevant government agencies/NGOs, and resource users on the importance and need for this exercise and obtain their active participation in future work.

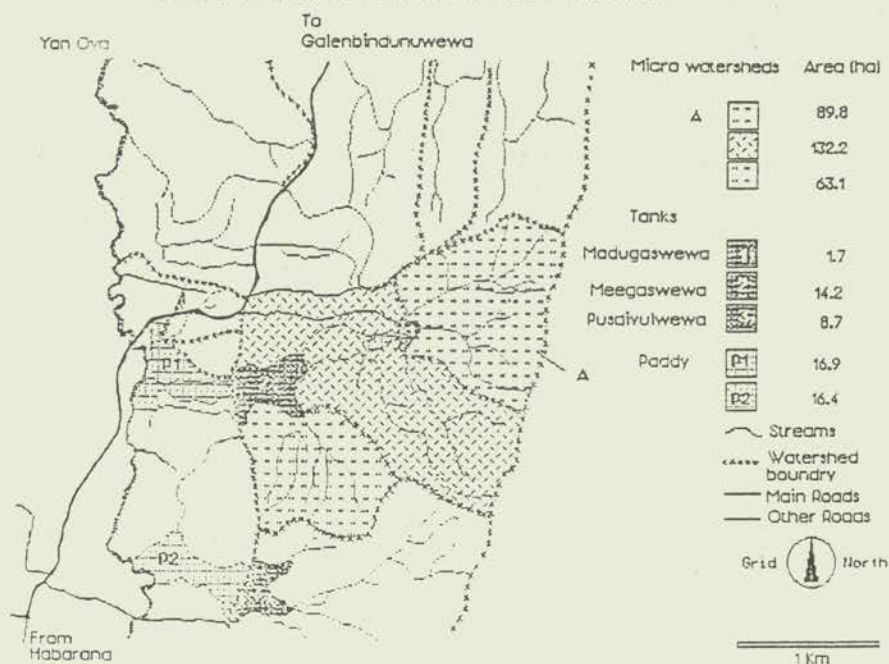
For this purpose, each group was provided with a line diagram/sketch map of 1:3000 scale with land marks indicating roads and streams for guidance. The groups collected data and mapped each land plot of a village. Refining of the map to maintain accuracy to scale was done subsequently by the draftsman supporting the group and the *map was used for participatory planning of resources management of that village*. Land and water use as well as other information collected through the participatory mapping exercise have been incorporated into the SCOR spatial database using a Geographic Information System (GIS). This was repeated for each village in selected sub-watershed system and for all selected sub-watersheds. For example, Figure 7 shows the pre-project land use (as of January 1994) by individual plot of one such sub-watershed, in this case a tank cascade system namely Maha Meegaswewa, MM. For this village, a participatory resources management "mini project" was formulated with an investment of Rs 1.2 million (US\$24,000). The project aims to change the *present land and water use pattern to a more profitable and diversified resource use combining production and conservation using appropriate technologies/techniques, novel shared control arrangements and resource augmentation*. New commercial enterprises and conservation practices in a typical sub-watershed in the Huruluwewa Watershed include: cultivation of medicinal plants, fruits and vegetables in *chena* (shifting cultivation areas), processing industry for medicinal plants, stabilized cropping patterns for *chena* and highlands, *contour bunds to cover the entire area*, water harvesting techniques, etc.

This means that the villagers in such pilot sub-watersheds have "action plans" that guide them along a path to the planned future from the current status of resources use. The planned future land use pattern is illustrated in Figure 8 while the current status (as of February 1995) is illustrated in Figure 9. Contour bunds and drains are being established to cover the entire extent shown in this map as well as in several other pilot areas.

Components of Conservation Farming and organic matter management (adopted by users) in selected tank ecosystems include:

- a) mulching (crop or weed residues) to increase soil moisture retention and to effectively use the limited rainfall and irrigation water. Promising results have been achieved in all sites: farmers managed to increase irrigation interval from 3 to 6 in chillies and from 8 to 16 in beans; time taken to reach wilting point was significantly higher when compared to areas without mulch; branches, leaves, flowers and pods per plant were significantly higher and consequently high crop yields have been achieved;
- b) adoption of contour bunds and drains and stabilization by biological means - as water harvesting/saving technique and for soil conservation.
- c) combination of agriculture and forestry. eg: through alley cropping, home gardening (forest gardens), growing seasonal and perennials between contour bunds in the uplands,
- d) green manuring,
- e) mixed cropping and integration of livestock,
- f) integrated pest management

MAHA MEEGASWEWA MICRO WATERSHEDS

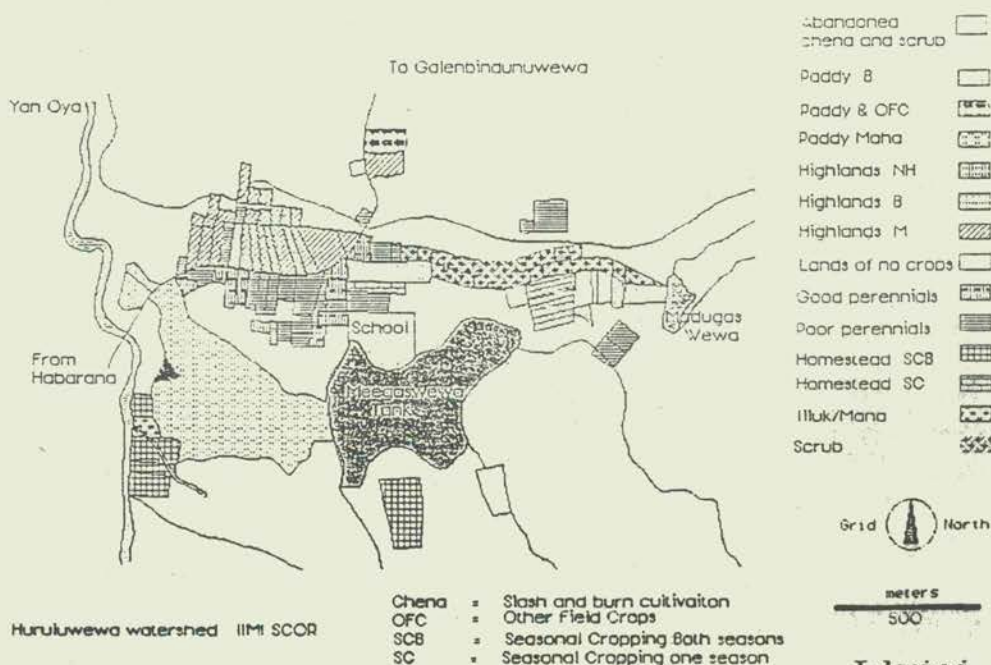


IIMI-SCOR March 1995 Mahameegaswewa Tank Catchment Area - 285 ha.

Idrisi

Figure 6

MAHAMEEGASWEWA LAND USE - JANUARY 1994



Huruluwewa watershed IIMI SCOR

Figure 7

PLANNED FUTURE LANDUSE FOR MAHAMEEGASWEWA

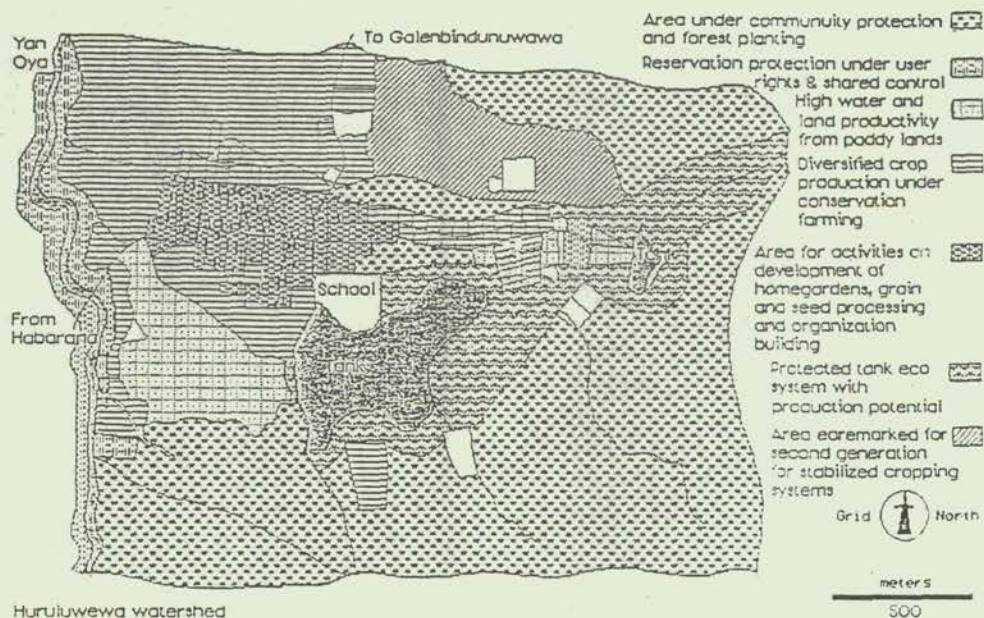


Figure 8

Idrisi

MAHAMEEGASWEWA LAND USE - FEBRUARY 1995

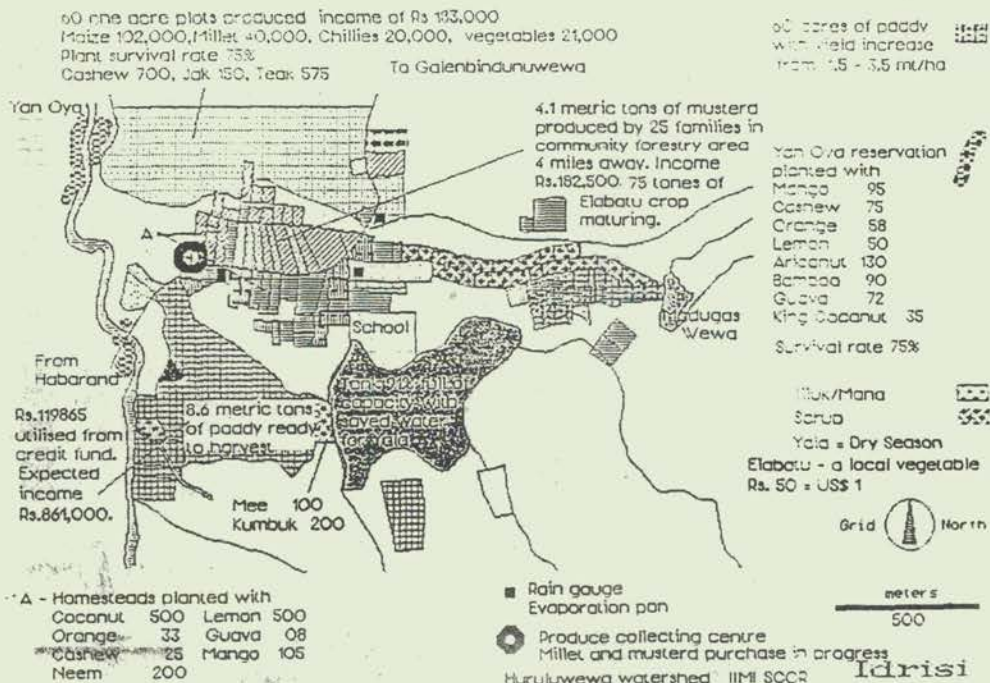


Figure 9

Idrisi

Novel modes of state-user partnerships in land and water resources use have been arranged. This mini-project is backed up by SCOR with a sub-grant of approximately Rs 400,000 (US\$8000).³ The banks have agreed to provide a loan four times larger than the SCOR grant for the user organization using the grant deposit as collateral. A Colombo-based company offered a forward contract to the user organization to purchase most of the expected produce under the "mini-project."

The main features of the tank ecosystems/sub-watershed production-protection plan or the "mini-project" that illustrate the elements of the proposed strategy are:

- (a) The action plan covers the entire geographic area of the sub-watershed (typically ranging from 200-1000 ha). It is intended to cover all the sub-watersheds or tank ecosystems in the major watershed.
- (b) It recognizes the function of each major segment of land use in the landscape, in the watershed context.
- (c) It recognizes the need for resource use change in each of these land segments for improving the livelihoods of all the people. Example: It involves all the families in the village in sharing the effort to change the present land use to a high-income and resource-conserving land use.
- (d) It has identified major zones for production, facilitating production planning and scheduling so that production activity can be organized enabling the organization to predict production, enter forward agreements, mobilize resources and exercise joint control over production, processing and marketing process with the membership.
- (e) It has a path for new technology to flow into the community to improve and balance protection and production. Example: For the first time the MM (Maha Meegaswewa) villagers were exposed to new knowledge from the SCOR teams on conservation farming. They shifted **chena** (shifting cultivation) farming from

³Providing small grants to the existing and new user groups is considered to be crucial. Such grants, among other things, will enable the group to:

- Show collateral when seeking additional loans through private financial institutions.
- Develop and promote insurance schemes for new crops, conservation schemes and investments.
- Construct storage facilities, markets, terraces, nurseries or other small physical infrastructure.
- Purchase equipment needed to initiate or upgrade joint enterprises to gain economies of scale and value added to their production.
- Join with other user groups to establish revolving funds for investments and/or the purchase of agricultural inputs.
- Obtain legal, financial and other services associated with establishing user rights, small enterprises and productive ventures.

Most of such "grants" will be transferred to new organizations after the completion of mini-projects. Hence, grants are used as revolving funds.

the catchment of their tank to a highland area and established organic bunds followed by earth bunds on contours with protective and productive plants and crops for a stabilized farming system that ensures a family food supply with maize, pulses and vegetables. In addition, valuable timber trees planted on boundaries provide security for the future. They tried mulch farming using straw in the rice fields raising a crop in yala season for the first time in their village.

- (f) It facilitates balanced disposal of economic activity in the village providing work opportunities to everyone. Example: The families have the opportunity to choose the economic activity based on the comparative advantages they have, stemming from the economic assets, including labor, skills that each family possesses, and family confidence in a particular activity such as rice farming, vegetable farming, livestock farming, trading, etc., or confidence (risk taking) in new ventures.
- (g) It facilitates organization and leadership, provides mechanisms of self-assessment and conflict resolution, increases the ability to analyze and predict, strengthens the bargaining capacity, and encourages risk taking in viable economic ventures.

A leadership emerged from the community with leaders of groups, organizations and companies aimed at production and protection (Figure 10) and volunteer catalysts representing each production zone in the village, which is the correct basis for selecting mobilizers without considerations of party politics. They have access to information from outside and knowledge gained from their own experiments in their own farms with the support of the government officers and others who extend such support to them. They can mobilize resources to carry out their plans and finally become shareholders of their own company with control over the production process, which is a productive way for small farmers to gain and share prosperity in an open economy.

Figure 7 A SCHEMATIC PRESENTATION TO ILLUSTRATE GROUP, ORGANIZATIONS AND SUB COUNCIL FORMATION IN A SUB WATERSHED

From Groups to Organization/Company to Sub Council Council

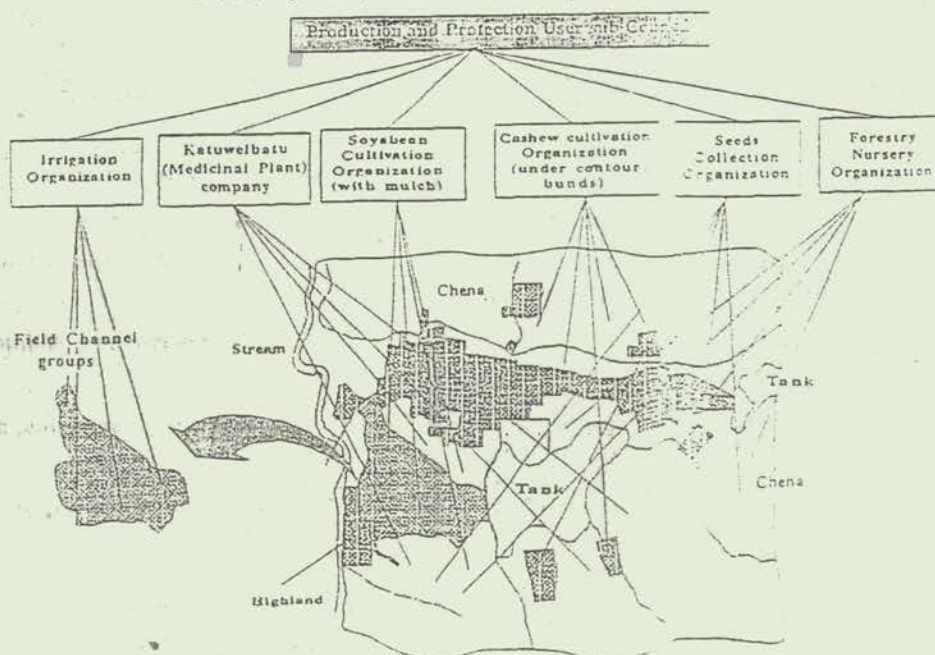


Figure 11 summarizes the SCOR process of testing strategies to integrate conservation concerns (mainly soil and water conservation) with production goals in a tank ecosystem context.

STRATEGIES/CONCEPTS:

1. Integrating Conservation Concerns with Production Goals: Balancing Production and Protection;
2. Watershed Focus : Tank Ecosystem Approach;
3. Shared Control : State-User Partnerships;
4. Participatory Integrated Planning of Land and Water Resources;
5. Proper Mix of Technology, Organizations and Resources;
6. Building Local Capacities;
7. Policy and Institutional Interventions.



Combined Effect on Activities

ACTIVITY AREAS:

1. Rice-Based Cropping Systems in Command Areas: Improve Cropping Intensity, Water Use Efficiency;
2. Stabilized Cultivation in Hitherto Shifting Cultivation Areas;
3. Conservation Farming in Homegardens;
4. Agro-Based Enterprises Coupled with Production and Protection.
5. Rational Mixing (over space + time) of:
Rainfall, Tank Storage, Ground water and Supply from River
Diversion

**Figure 11. Integrating Land and Water Resources Management
in a Watershed/Tank Ecosystem Context**

REFERENCES

- Brohier, R.L. 1934 - Ancient Irrigation Works in Ceylon Colombo, Ceylon: Government Press
- Dikshit, D.D. 1986, Agriculture, Irrigation and Horticulture in Ancient Sri Lanka, UPASANA Printers, Delhi.
- Farmer, B.H. 1967, Pioneer Peasant Colonization in Ceylon : Oxford University Press
- Gooneratne W., P. Wickremasekara, M.Samad and C.M. Wijayaratna, 1980, "Rainfed Farming in the Dry Zone of Sri Lanka", Agrarian Research and Training Institute, Colombo, Sri Lanka.
- Tennakoon, M.U.A., 1974. "Rural Settlement and Land Use in North Central Sri Lanka, Unpublished Thesis, Syracuse University, Syracuse, N.Y.
- _____, 1986. Drought Hazard and Rural Development, Central Bank of Sri Lanka.
- Sakthivadivel, R., Nihal Fernando, C.R. Panabokke and C.M. Wijayaratna, 1994 "Guidance Package for Water Development Component of Small Tank Cascade Systems", Unpublished project report, International Irrigation Management Institute.
- Widanapathirana, A.S. "Water Harvesting in Sri Lanka and Sudan, TIEMPO, 5:5-10.
- Wijayaratna, C.M. 1994. "Integrating Environmental and Conservation Concerns with Production Goals A Participatory Approach to Land and Water Resources Management in a Watershed Context", Paper presented to the 8th International Soil Conservation Conference on "Soil and Water Conservation: Challenges and Opportunities, December 4-8, New Delhi, India.
- _____, 1995. "A Participatory Holistic Approach to Land and Water Management in Watersheds - Paper Presented at a special seminar on "Effective Water Use through Improved Irrigation Management Information System", Irrigation Engineering Center, NIA Compound, EDSA, Quezon City, Metro Manila, 13-15 March 1995.

THE COORDINATE GROWTH BETWEEN THE DEVELOPMENT OF WATER RESOURCES AND SOCIAL ECONOMICS IN DALIAN

Luan Weixin

Dalian, Located on the south of the Liaodong peninsula, which is an important window of opening to the outside world and the center of traffic, trade, finance and tourism in northeast China. It has been provided as a strategic aim to establish the "Hongkong" in north China. But the supply and demand contradiction of water resources is appearing clearly in pace with the expansion of economic scale. Which does not only affect the normal life of people, but place restrictions on the development of regional economics. This paper tries to provide some views about how to coordinate the relation between the development of water resources and social economics in the Dalian region.

1. The conditions of fresh water development are poor, the ones of sea—water utilization are good

(1) The fresh water resources are shortful, the development conditions are poor

The total amount of fresh water resources in the Dalian region are approximate to 3.76 billion m^3 , which includes 3.48 billion m^3 surface water and 0.884 billion m^3 groundwater (the duplicate amount is 0.58 billion m^3). The amount of water resources in this region are approximately to 700 m^3 per year for each person, this average is respectively equal to the percentage of world, China and Liaoning province 9%, 28%, and 70%. According to the types of average water resources, Dalian is at a very low level.

The development conditions of fresh water in the Dalian region are poor, we can see them from the following: ① The tail of the Qianshan mountain chain runs through this region from northeast to southwest, which is the main backbone of landforms in this region, from this axis the terrain drops down respectively to the southeast and northwest, thus form the stratified landforms structure (including middle mountains, low mountains, hills and tablelands). On this condition, the turbid rivers whose distance of flow is near to 30 KL are formed, the fall rate in length of those rivers is big, the ability of regulation and storage is low. It is not easy to interchange be

① Luan Weixin is an associate professor at the department of Geography, Liaoning Normal University, Dalian, China.

tween surface water and groundwater resources. Then the concentrated development of the runoff of water system is difficult.

② On the basis of the quantitative analysis of the perennial climate data in Dalian, we infer from the long—short cycle of the space—time order of precipitation in Dalian, The conclusion is that Dalian is both at the latest period of the ascending stage in 1980s long circle of yearly precipitation and at the falling period of short circle (in those several years in the end of this century) which belongs to the shortful precipitation stage.

③ Because this region is affected seriously by the east Asia monsoon, the precipitation imbalance of seasonal distribution and yearly distribution is formed. The precipitation concentrates mainly between June and September (flood season), the precipitation in those four months is approximate to 80% of the whole year, the one in the other eight months is 20%. The change of precipitation between years is more greater. The biggest amount in 1914 is 1124 mm, the smallest amount in 1957 is only 318 mm, the difference between them is 3.5 times. And the continual high water years or low water years often appear.

The water resources per man in this region is not enough, the condition of converging water in surface is poor, and the precipitation appears the bigger yearly change and seasonal change, thus the full utilization of limited water resources is more difficult.

(2) The conditions of sea—water utilization in Dalian are good

① Dalian is located on the south of the Liaodong peninsula, the jointed area of sea and land is big, the land coastline can reach 890 KL, the industry extends basically along the coast of Dalian Bay and Dayao, Xiaoyao Bay, This provides convenient conditions for utilizing sea—water;

② The coast is largely rock coast, it's feasible for the chemical demands to set up the diversion facilities on near coast, this can save many investments of building a lot of drawing tide gully and drain ditch, etc. in silt coast, ③ The temperature of sea—water along the coast is low, there are approximate to 7 months in which the temperature is below 15°C, the effect of using as industry cooling water is good.

Dalian has a long history in utilizing sea—water, in 1930s sea—water had been utilized as the indirect cooling water for some industry departments, such as chemical industry, shipbuilding, electricity, etc. The range of sea—water utilization extends continually along with the progress of science and technology of new China, some diversion projects are built again and again. At present, there are 26 enterprises to draw sea—water, the amount of using sea—water every day is 1.7 million ton the amount of using sea—water per year is 0.6 billion ton, this relaxes the contradiction of urban water utilities, this is approximately equal to add 10 million yuan of economic capacity.

2. The relation between the development of water resources and regional economics development is not coordinated.

The supply and demand contradiction of water resources in the Dalian region have been brought out. Although it is related to the smaller natural precipitation in this region, the bigger e

conomic density, and the unsuitable measures of tapping new resources and economizing on expense. But the main reason is that the relation between the development of water resources and regional economic development is not coordinated. This can be shown in the following three respects:

(1) Water resources are not suited to the space distribution of population and economics.

The precipitation and the depth of runoff basically have the trend of dropping down progressively from northeast to southwest in this region. The perennial average precipitation in the region south to Jinzhou is 600 mm, Zhuanghe, in the northeast Dalian, raises to 800 mm. The depth of perennial runoff raised from 100~200 mm per year to 350~450mm per year. And the condition of concentrating utilization of surface water in the region south to Jinzhou is poor.

Table 1 Relative indexes in the region
South to Jinzhou and the north region

items regions	precipitation (mm)	the depth of runoff (mm)	the rate of producing water per year (m ³ /km ²)	the average water per year (m ³)	the amount of water per 10,000 yuan (m ³)
The region south to Jinzhou					
600	100~230	231000	209	156	
The north region	630~800	230~450	450000	1700	3009
The average of the whole region	633	230~450	291000	700	869

The distribution of water resources and the one of population and economic density is just opposite in this region. The center of economics and population is at the peak of the Liaodong peninsula, the trend is dropping down from southwest to northeast. The average population density in the region south to Jinzhou is 1180 per kilometer. The average water resources are 200 m³ per year. But the average water resources in north region is 1700 m³ per year.

The imbalance distribution between water resources and population and economics results in an unreasonable development in the Dalian region. It must depend on long—distance water transfers to resolve the problem of urban water utilities. Thus the cost of urban water utilities is raised.

(2) The structure of water utilities is unreasonable. This mainly refers to the inconsistency between general development trend of social economics and the distribution of water resources among departments.

Table 2 GNP and departments of using water in the dalian region.

item \ department	industry	agriculture	the third industry
% of total water consumption	22	64	7
% of GNP	50	13	36

The total water consumption in Dalian in 1993 is approximate to 1 billion m³. agriculture: 621.2 million ton; 64%, but the output value is only 13% GNP; the third industry: the water consumption is very little, only 7%, the output value is 36% GNP, the additional value per ton is 25 times of one of the agriculture. The third industry is a developing economic department and is at the urban area in which water resources are shortful, however, the limits of using water are the most strict. On the contrary, some abilities of saving water in agriculture are still not dug out.

The structure of using water in broad region north to Jinzhou is seriously unreasonable. The total water consumption is 0.565 billion tons, agriculture is 88.7%, industry is 8.9%, urban life and the third industry is 2.4%. It is basically on the crude conditions of water utilities.

The unreasonable structure of using water can also be seen in the inside of the first, second and third industry. In the inside of industry, the water consumption per 10,000 yuan of mechanical industry is 15m³, metallurgical industry is 335 m³, power industry is 1150 m³, chemical industry is 428 m³. At present, the output value of chemical industry is 24% total industry output value, metallurgical industry is 7.1%, power industry is 5%, that is to say, the bigger water consumption departments are more important in industry structure, but the high and new technological industry, such as chemical industry and electronics industry, is not important. In the third industry, catering trade consumes a lot of water, the water consumption per bed is 8~10 tons in normal hotel every month, at present, catering trade has high rate in this region, But the other levels of the third industry has low rate, though the water consumption of them is smaller.

(3) The development of water resources falls behind the regional economic development

Water resources are the main factor that limit the regional economic development, especially in urban areas, the supply and demand contradiction is very outstanding. Since 1970s, water shortage almost appears in Dalian every year. The industry output value has been cut down for 100 million yuan. The water for people's life also has no guarantee, even take water at night for a long time, some people have no water to drink for several days. Although this phenomenon is related to the measures of saving water, the main reason is that some people have no predict consciousness of water sources development, and the water conservancy facilities and diversion projects fall behind the economic development.

The government of Dalian city has planned to invest 3 billion yuan to build the third stage of diversion of Billu river. But on the basis of present economic structure and the rate of economic development, the problem of water shortage will appear again after 2000 years, the water consumption will reach 2 billion tons in 2010, which is equal to 52% perennial average water resources. Although we can depend on building or extending water facilities, it's still difficult to set

tle this problem. The condition of water resources supply in the Dalian region will change from falling behind economic development into absolute water shortage.

3. Coordinate the relation between the development of water resources and regional economic development

On the basis of analysis of the conditions, the current situation of development, and the demand of social economic development of water resources in the Dalian region, from this time to the end of this century, the water problem can be solved by building the third stage of diversion of Biliu river and by building some new reservoirs, such as Dongfeng reservoir, etc. If we want to offer the guarantee of regional economic continual development, we must depend on coordinating the relation between water resources development and social economics, and forming economic structure type of saving water. In view of this analysis, it seems valuable to grasp this gap chance in those years before the end of this century. We must reinforce the building of some hard wares, such as water conservancy facilities, etc. to guarantee the trend of economic development. We must also use this period of time to regulate in time the structure and space distribution of social economics, and to coordinate the relation between water resources and regional social economics. To achieve those goals, we must do the following works:

(1) Reinforce the management system of water resources

① Reinforce the centralized management of water resources. It includes industry policy and regulation of the functions of organization of water resources. To industry policy, water industry department is an important basic industry department, just like power, agriculture, and metallurgical department. The overall planning and multi-aim synthetical development should be carried out in water industry department. All links, such as water resource, water supply, water utilities, water disposition, should coordinate and arrange integrally. According to those measures, the policy and measures of aquatic products industry should be carried out. To organization management, a brand new management mechanism should be built, which can manage all links of water resources, such as development, disposition, supply, and utilization. We must improve the independence of the operating water enterprises and drift apart the contacts between government's finance and the water enterprises. Then they can change into a movement mechanism with high benefit and high income.

② Build the information system of water resources management

It's unsuitable for modern scientific management of water resources to depend on the extant qualitative management type. It's necessary to build a suit of information system in which computer's softwares are supporting structure. This can finish on the basis of extant plentiful basic data and the fruits of scientific research. Thus both the basic data and the related data can be input into computer. Through the building of information system of water resources, water resources—environment knowledge system, management decision system of water resources, etc. the management of water resources in the Dalian region will reach the level of synthetic, model, computer and multi-aim. It can provide scientific decision consulting opinions for related com

partment and trace the dynamic progress of demand and supply balance of water resources.

On the basis of finishing management information system, through some methods, such as multi-aim planning, we can manage systematically the group of surface reservoirs, the connection net management of surface water-groundwater resources. We must especially pay attention to the systematic regulation and storage and the dispatch of high water year and low water year, high water stage and low water stage, surface water and groundwater. Then we can reach the aim of reasonably using water resources and reducing the cost of water resources development to the lowest point.

③ Reinforce the commodity sense of water resources development. Water is not only a natural environment condition, but an important crude material. So water fee should include the cost of water supply and the resources fee. At present, water fee in the Dalian region is below to water supply cost, which will result two problems. One problem is that water fee is only a small part of the cost of using water, which reduces the motive force of using water department. The most part of the macro-economic benefits, social benefits and ecological benefits of water resources transfer to the using water department. Thus, it covers the wasteful acts of them, they also would rather not invest much money on saving water facilities, so the supply and demand contradiction of water is more outstanding. The other problem is that the water price is so low that water supply department can't retrieve its investments, income falling short of expenditure, which limits the expanded reproduction of water department and seriously dampens its enthusiasm. So we must look law of value as lever and establish the reasonable water price. We must also eliminate the situation that water price deviates from its value and improve the beneficent circle of the inside of supply water department. At the same time, we also advise that the differential water price should be made on the basis of regional different cost and condition of water supply, which can create favorable conditions for improving the regulation of transferring water consumption department to rich water region.

(2). Regulate economic structure and internal structure of industry

On the basis of economic structure and the situation of using water in Dalian, the general economic structure should define the aim of extending the third industry. The reasons are: ① The third industry department is the smallest water consumption department. On the case of equal water supply, the biggest synthetical benefits can be achieved by extending the third industry. Some industries, such as finance and insurance synthetical technology product service real estate and public utilities, etc. should be especially extended. ② Dalian has fixed the aim to establish the "Hongkong" in north China, which demands not only building the economic and technological contacts with many regions in China, but also walking on the international economic arena and working as the center of trade finance information and tourist in northeast Asia. According to this change, Dalian should change from product center into service center and vigorously extend the third industry departments.

In industry production, the water consumption per 10,000 yuan of electronics, mechanism

and other high and new technology industries is below 10 tons. those industries are low water consumption departments. they are also the rising sun department of industry, those industries should be extended progressively. But the water consumption per 10,000 yuan of power, chemical, metallurgical, etc. is 300~1000 tons, the latter is tens times of the former. At the same time, those industries are the setting sun industries in the developed regions, they should be reduced progressively.

In the regulation of economic structure in the Dalian region, whether we can use sea—water should be looked as an important basis. Although the water consumption of some chemical and metallurgical enterprises is very big, most of them can be replaced by sea—water, so they should be supported vigorously. The technological reform and equipment import of the product items in which sea—water can be used should be offered loans on favorable terms.

(3) Regulate the industry distribution

To settle the problem of urban water utilities and industry water utilities in the Dalian region, in addition to the above—mentioned measures, the space distribution of industry must be regulated progressively, too. It refers to limit the development scope of urban population in the region south to Jinzhou; to limit the development of industry departments which consume a lot of water, to transfer water consumption industry departments in a planned way to some industry reserve bases, such as Pulandian, Zhuanghe, to develop the third industry in urban areas and finish progressively the transformation from product type to service type. Through the regulation of industry distribution, the situation that the imbalance between precipitation and population and economics can be changed, thus long—distance water transfers can be avoided to some degree. At the same time, the using water industry departments, such as sea—water synthetic utilization, chemical sources, etc. should be transferred to coast areas.

COMMUNITY INVOLVEMENT IN THE CONSTRUCTION OF FERROCEMENT TANKS - THE CASE OF MASWA DISTRICT

E.J. Chaggu
Centre for Housing Studies, Ardhi Institute
P.O. Box 35124, Dar es Salaam, Tanzania

1.0 INTRODUCTION

The term community is defined differently by many scholars to suit their own perspectives. However, Phillips (1969) said that, community is any circle of people who live together, who belong together so that they share, not this of that particular interest, but a whole set of interest wide enough and complex enough concerning their lives.

In Tanzania, community involvement is a commitment to the policies of self reliance, decentralization and participatory approach which utilize the existing structures and local leadership according to Muhungutwa (1994). The construction of ferrocement tanks in Maswa, involving the community, was therefore in line with the governments policy. It was regarded as an important step in the construction due to the nature of the settlements and labour requirements.

Life in Maswa villages is of scattered nature. Families live in dispersed settlements due to livestock keeping and agricultural activities. They are completely tied up by those works in addition to fetching water from very far areas during the dry season. The faced water problems by Maswa Community can be seen in the attached photographs. People dig manually up to 25 metres in efforts you seek for water.

Muhungutwa (1991), asserts that, in any community based project, there is active rather than passive engagement by the beneficiaries in the project activities. He emphasizes that, a high level of involvement of community people, a considerably high degree of decentralization in decision making, as well as the development of effective mechanisms or expression of people's needs and demands are all empirical. When beneficiaries, are involved in all stages, they tend to identify with the project as theirs. Accountability is therefore, a logical consequence. The experience gathered in Maswa is explained in the following sub-sections.

2:0 COMMUNITY INVOLVEMENT

The construction of ferrocement tanks in Maswa had at the back of the mind an objective of creating community awareness about the importance and benefits of rainwater harvesting for multiplier effect purposes. The political set-up of the country offers a good opportunity to anybody who would like to work with the community.

For example at village level, the set-up is as shown below.

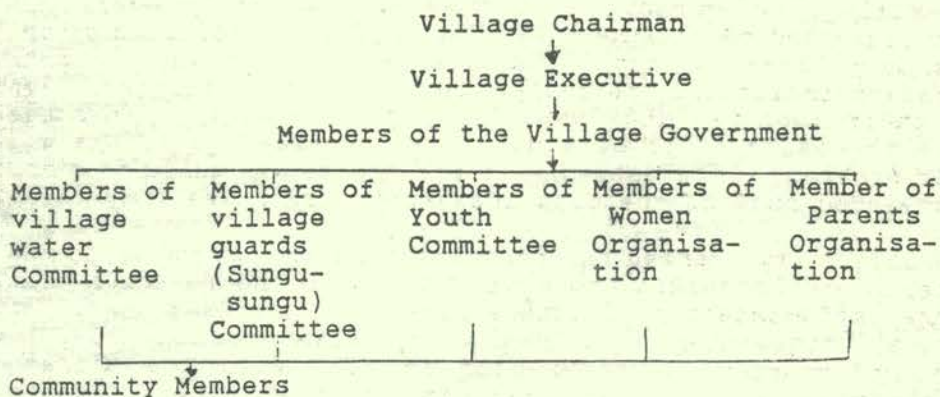


Chart 1: Village organogram

From this set-up, one can work very easily with the community by channeling the need through the village chairman. In Maswa, the situation was handled in the following manner.

2.1 Discussion with District Officials

It is common in Tanzania to get a letter of authorization from the district officials before starting any activity in the villages. The research team therefore, made a visit to the Maswa District offices where a discussion took place between the District Commissioner (DC), District Administrative Officer (DAO) and the District Community Development Officer.

They were briefed about the chosen sites for the construction of tanks in the villages. They gave a very constructive idea about the suitable location of tanks. They said that, despite the choice of the villagers, we should advise them on health reasons, not to construct the tanks in places closer to cotton storage or within the buildings used to store cotton. This is because of possibilities of contaminating rainwater by cotton dust and the chemicals used in cotton production. It was a very useful proposition which altered location of tanks in some places.

They went further to propose that, one tank be built within the Maswa Headquarters premises for possibilities of multiplier effect. It is an area where many people are passing and therefore appetite to copy the technology can be raised easily.

Thereafter, an official letter was given to us which introduced us to the village leadership.

2.2 Meeting with the village leadership

The village government received the researchers with much enthusiasm and bought the idea of changing the location of the tank as proposed by the DC whenever needed. It was a smooth operation indicating the respect and trust the villagers have for their leaders. They were quick in choosing other areas where the tanks could be constructed in order to reduce the water problems. Interestingly, their choice was quite fair and open minded showing the good leadership qualities they have.

The leaders implemented the former plans made, of choosing the artisans and labourers who could work with the research team in the implementation of tank's construction. They saw to it that, all activities undertaken were carried out smoothly. It is very important to work hand in hand with the village government as it is quite rich in information about their premises and knows the people better. I would say that, it was a joy to work with them. We need not to by-pass them in implementation of different projects.

3.0 TANKS CONSTRUCTION AND THE COMMUNITY

The construction phase, of 20m³ capacity ferrocement tanks was a combined effort of technocrats, village artisans and labourers. Each tank required a minimum of 9 days due to weather conditions. They were constructed closer to the rainy season.

The community were quite happy about the tanks to an extent that, they were always around to see how they are constructed. They demanded to get a written manual on the construction. The on-site training given was not enough. This idea raised a need to translate the used manual into Kiswahili (Local language) from English. The research team are happily doing the translation work at the moment.

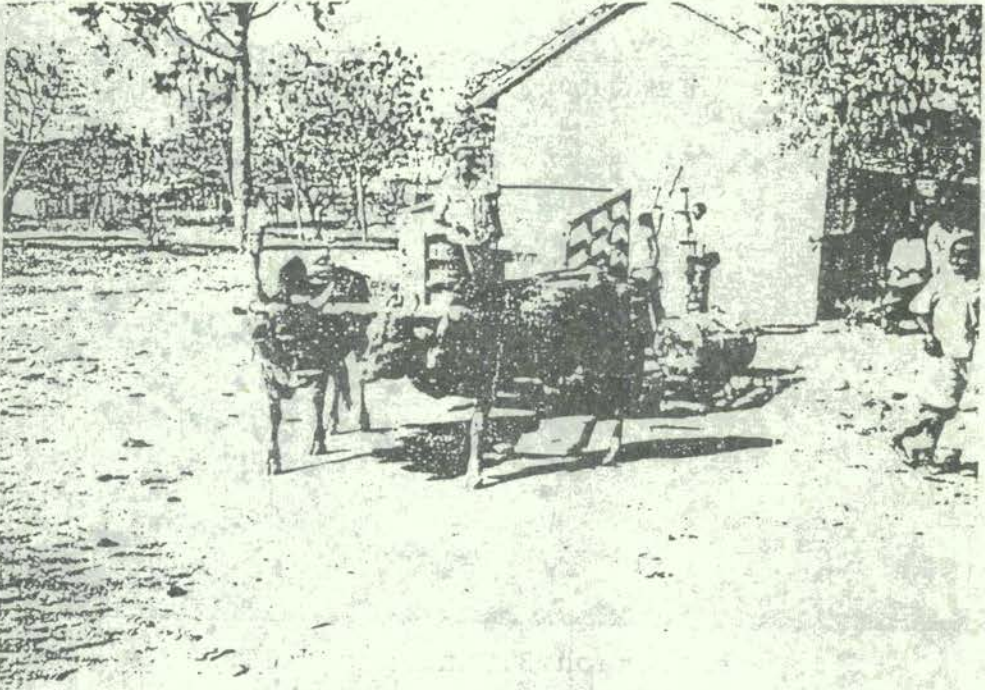
The construction work with the community involvement was as explained in the following photographs.

Photograph 1: Water to Site

The availability of water for construction in Maswa was facilitated by using ox-carts as seen in photograph 1. The owner of the cart is one of the villagers. His child is the one who directed the cows to the site.

Photograph 2: Cleanliness of the water

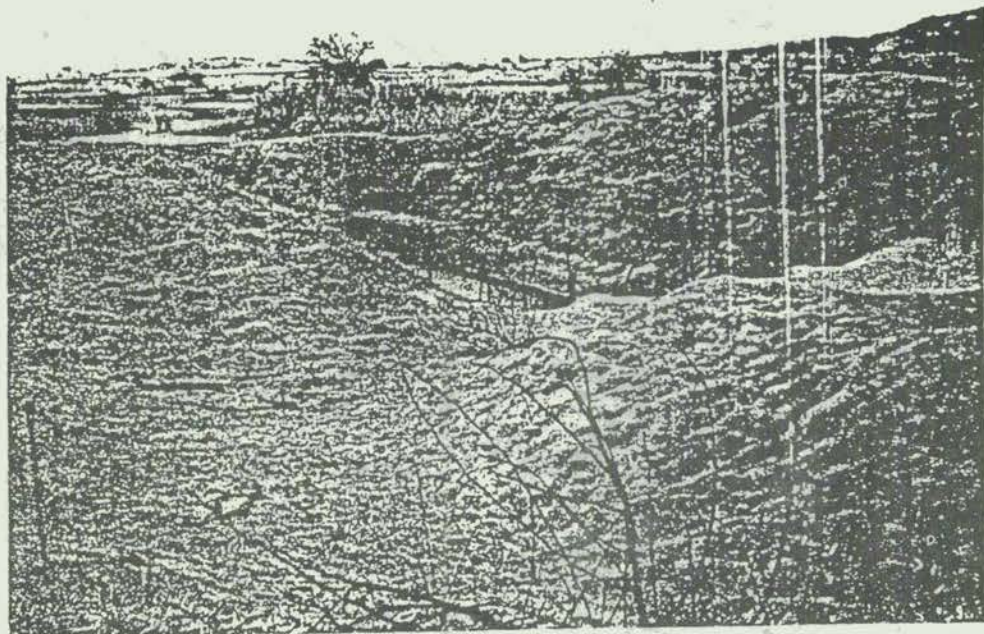
As seen in photograph 2, some of the community members were around when the author (touching the water) and other construction team member (standing with blue cap) were checking the quality of water for tank building purposes. The colour of the water, milky type, indicates the acute shortage



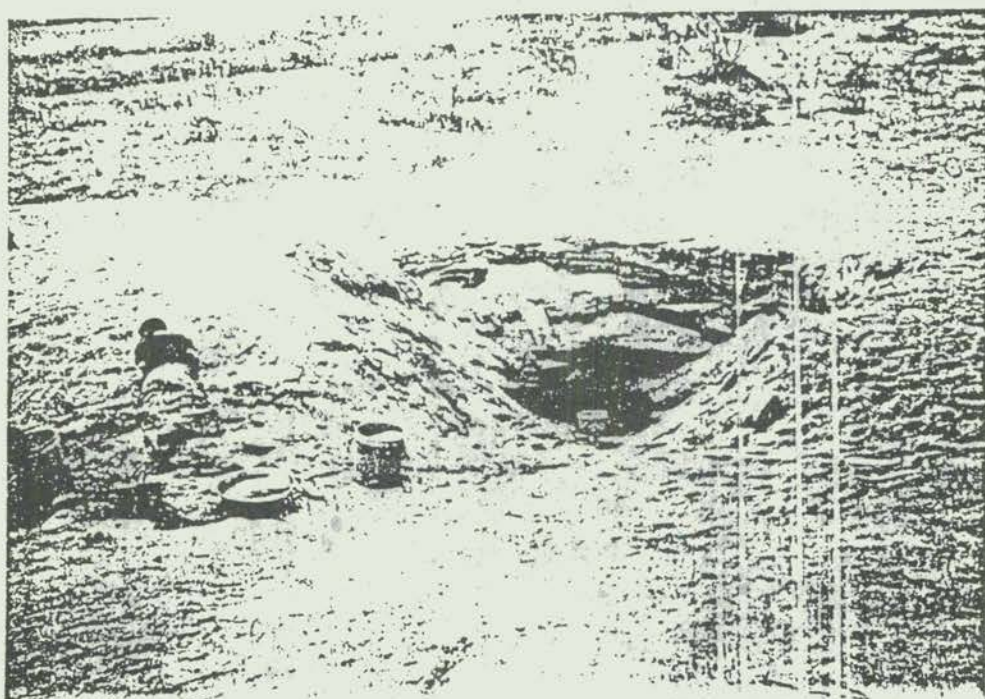
Photograph 1:Water to Site



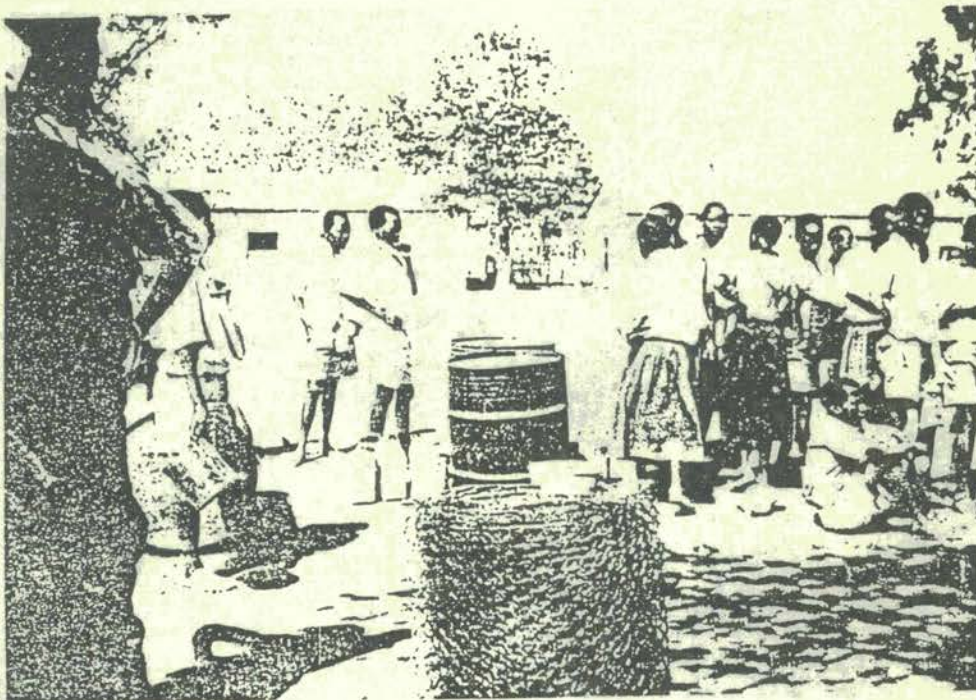
Photograph 2:Cleanliness of the Water



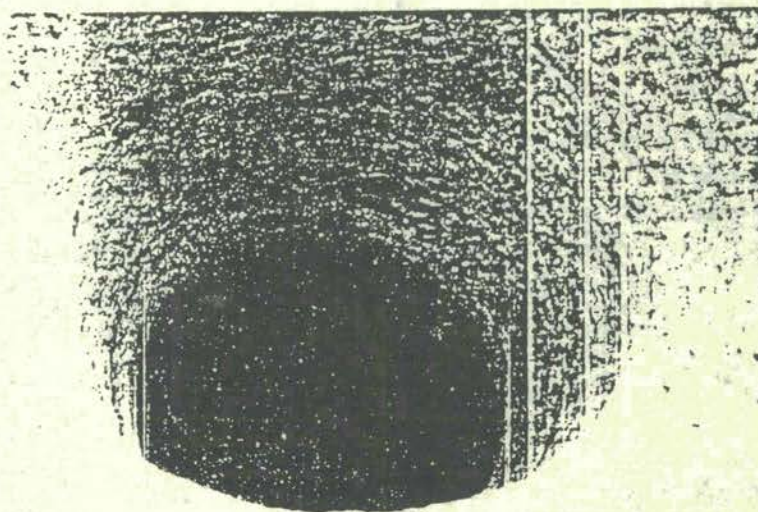
Photograph 3:Hand-dug wells



Photograph 4:Gender



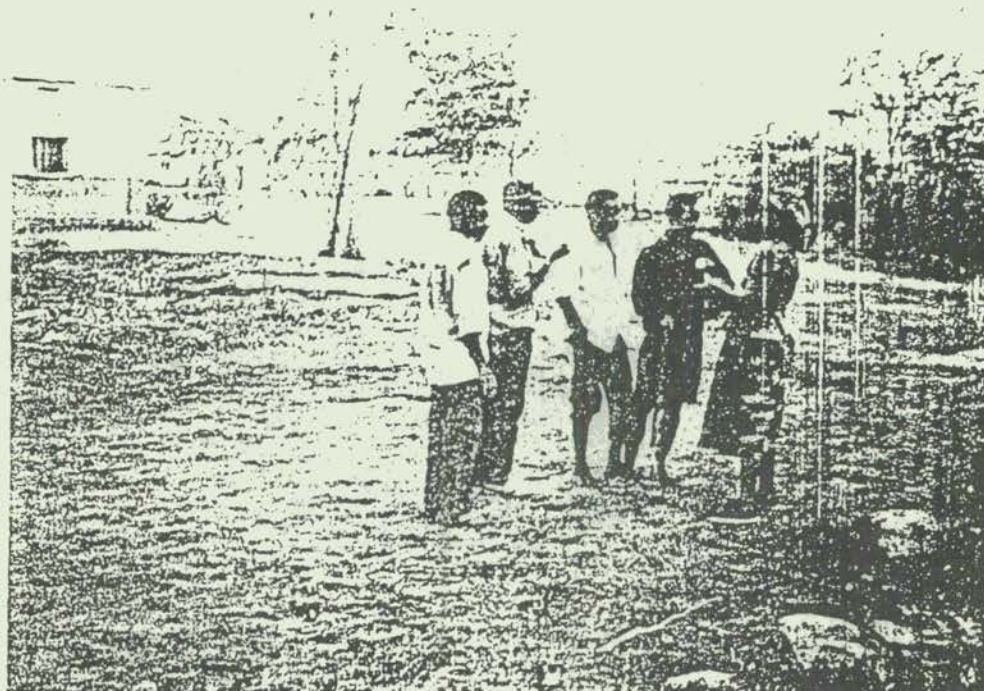
Photograph 5: Further efforts by the Community in looking for water



Photograph 6: Environment



Photograph 7 :Community Briefing



Photograph 8:Community Briefing

of water in Maswa District. It was collected from hand-dug wells. The colour is mainly from mud. This water was not suitable for concreting, a vehicle had to go as far as 40 kilometres in order to get water of at least good quality for concreting work.

Photograph 3 Hand-dug wells

Water fetching efforts by the Maswa Community during the dry season in Maswa. This digging was done in the river bed. Most of the rivers dries up during the hot weather. This photograph shows the acuteness of the problems people face. People of the shown area are lucky because there is a river bed around, others walk as far as 8 kilometres in order to get the well needed liquid. This was dug for household use and cattle drinking.

Photograph 4: Gender

It is clear from the photograph that, women are the prime collectors of water. In fact the children as well despite their sex help their mothers in fetching water as seen in photograph 5. In many cases, the people who dig for water extraction are either men or cattle keepers. This photo was taken by the author upstream of photograph 3.

Furthermore, the photograph shows the type of containers used for water collection to the homes. They vary from 5 to 20 litres. It is a very small capacity for household use and therefore, rainwater tank's construction becomes a savior of the people. The lady in the photograph have already filled two containers and the water is finished in the hole; she decided to wait for water to fill the hole for her to collect more.

Photograph 6: Environment

The haphazard digging of wells destabilizes the soil and causes it to be susceptible to erosion during the rainy season. This area happen to receive very heavy rains to an extent that, the villagers grow rice.

Photograph 5 shows further efforts by the community in looking for water. The person inside the hole of 1 metre diameter is 20 feet deep (6 metres); he has not found the water and therefore continues to dig using hand-tools. This hole, which will remain unlined, will cause havoc to the environment during the rainy season.

Photograph 7 & 8: Community briefing

Before the implementation of the work, that is, tank's construction, community awareness was regarded as an important component of the project. In this photograph, the author (1994) was talking to the pupils of Sayusayu Primary School in Maswa. She was explaining to them about the implementation phase of Rainwater Catchment in Tanzania. This helped to raise

the awareness and co-operation in the activities which needed their contribution.

In photograph 8, the author briefs some of the community members on what is expected from them as regards the construction. They were given chance to air their ideas and comments.

The community worked hand in hand with the technocrats and managed to complete seven, twenty cubic metre ferrocement tanks and eight fragmented tanks.

4.0 PROBLEMS

The community members are ready to be involved in any activity going on within their premises. They can however, be very problematic if one do not handle them properly. Some of the problems that can be faced include (the list is not exhaustive in anyway):-

4.1 Food

The construction work involves expenditure of a lot of energy, it is therefore important to get arrangements of food for those concerned with the work. This is necessary because some villagers come from far and food is scarce during the dry season. For maximum expenditure of energy, food is of paramount importance.

4.2 Communication

The communication as regards the activities or work going on in order to avoid confusion on site is necessary. It irons out bad temperaments of people. In some cases misunderstanding was about to happen between the foreman and the community members, simply because there was not enough communication between them.

4.3 Information

People believe that "information is power". When proper information is given to people/community, their output of the work becomes quite encouraging, even the quality of the construction work changes for better. It is therefore good to give the community enough information for them to get a platform to work on.

4.4 General Foreman

Without a general foreman to move with, from site to site loss of tools can occur. This person helps in controlling the working gears and to show some construction steps whenever

needed. He has been very useful in Maswa work in that, when a village do not have a proper artisan, he takes over the work. It facilitated the work very nicely.

4.5 Loss of tools

Tools can be lost through theft or damage during the work. The former case, can be restricted by careful handling of tools and, the later case, as it depends on the production quality of the tool, less can be done. However, the tools should be used and handled with great care.

4.6 Double use possibilities of building materials

The site experience have shown us that, the materials used for tank's construction purposes, fetches a high priority of building other things in the community areas. For example, the chicken wire mesh, people requested it for their window coverage or chicken shed building. Cement, people required it for plastering and flooring their houses and so on. One needs to oversee such problems in order to avoid loss of building materials.

4.7 Storage of materials

The place where the materials are stores should be accessible enough to the users. In some cases, the store keeper had to be looked for, for almost half an hour. Such a practice delays the work. The materials should be stored closer to the working place in order to avoid delays and transport costs.

4.8 Transport

Transport of materials and the building team causes alot of difficulties if not well planned. Cases have occurred where, a vehicle was needed to go as far as 40 kilometres in order to fetch water for construction purposes.

The transportation element should not be forgotten. In order to move materials from the storage place to site.

4.9 Community Leadership

If the community leadership does not have approval of the community all the projects at that level are going to face problems from the people. This is however, applicable in the Tanzanian context only. The work done in Maswa however have not faced such a problem.

5.0 CONCLUSION

The conclusion, it is worthy to note that, working with the community at grass-root level is very important for sustainability purposes. It is however, necessary that, careful handling of the village members that is, respect, is practised and given high priority.

REFERENCE

1. Chaggu, E.J. et al (1994), First Technical Report on Rainwater Catchment/Tanzania II, The Centre for Housing Studies, Ardhi Institute.
2. Muhungutwa, M (1994), A paper on Community Participation in the implementation of environmental programmes, CHS, Ardhi Institute
3. Muhungutwa, M (1991), The field practice of community participation. Factors that influence community. Participation in Community - Based Practice.

An Analysis on the Effects of Building the Ponds for Gathering Rainfall on the Upper Reaches of The Huaihe River^①

Guan Hua, Zhao Bingdong, Shi Zhaoli^②

1. The Posing of the Questions

The Precipitation variability in the regions of the Huaihe River's upper reaches is large, the water amount there is concentrated, the tributary of the river system is short, the speed of sinking flow is fast. There are some questions like the non-conveyance system of the water conservation, the low standard of the flood-control, the inadequate capacity of the flood discharge and so on. The flood and waterlogging and the drought take place frequently. According to the data from 1470 to 1980, the frequency of the occurrence of the flood and drought reaches 70%, of which the frequency flood and waterlogging accounts for 38.5% and the frequency of the drought accounts for 31.3%. In order to adjust the runoff of the river and effectively prevent and control the disasters of the flood and the drought, the large-scale construction of the water conservancy projects has been undergone, many irrigation works, mainly the large-scale reservoirs, have been built in the region since 1950s, and they played a great role in course of preventing and controlling the disaster of flood and drought, the farmland irrigation, the water supply in cities, and the aquaculture, the navigation etc., and notable benefits have been made. However, Some unfavourable questions have been raised by building the reservoirs, such as the question of the changement of the ecological environment, the huge constructive investments, immigration, the submergence of the cultivating land, the deterioration of the living environment, and so on. Especially, when a catastrophic storm emerged, instead of playing a part in reducing the flood, the reservoirs can even cause more serious flood disaster because of the fully flood discharging or the bursting of the dams and the increasing of the flood peak's discharge. The typical example of this is the catastrophic flood-storm of "75.8", during which the water level of each tributary of the upper reaches of the Huaihe River rose so rapidly that 2 large-scale reservoirs (the Banqiao Reservoir and the Shimantan Reservoir), 2 medium-sized reservoirs and 58 small-sized reservoirs collapsed successively, and led to the tremendous loss of people's lives and properties. Therefore, in recent years, some scholars were suspicious about the role of the reservoirs, even some scholars thought that unless properly being used, the favourable water conservancy project can turn into "detrimental water conservancy project". As to the regions on the upper reaches of the

① The Project is supported by National Natural Science Foundation of China

② Department of Geography, He'nan University, Kaifeng, 475001, China

Huaihe River, it isn't sufficient that people depend only on a few key reservoirs, and some other types of projects also should be built coordinately, and the prevention of the flood and the drought should be put into effect. On the top of some gully of the hilly lower-mount regions in the southern part of the Huaihe River's upper reaches there are some ponds for gathering rainfall seasonally. This is a kind of small-sized irrigation works served for irrigating the farmland, and consists of pond and dam. In order that the farmland of the lower part can be irrigated by drawing water, it is usually located on the top of the gully. Its volume is small, mostly between $3000-12000\text{m}^3$, its water area is between $1000\sim 3500\text{m}^2$, its water depth is between $2\sim 4\text{m}$. Practice shows that these ponds for gathering rainfall can not only be used in irrigation but also can play a part in preventing the flood and waterlogging. If a large number of such ponds are built, they will become an ideal kind of coordinated project form for the reservoirs and can partly replace the role of the reservoirs. Compared with the building of the reservoir, the building of the ponds for gathering rainfall can get greater benefits on the aspects of the conservation of water and soil, the economization of the funds, the saving of the cultivation etc. We will discuss the effects of building the ponds for gathering rainfall in the following part by comparing with the building of reservoirs.

2. Analyses on the Effects

Building the ponds for gathering rainfall on a large number to complement part of the reservoirs' function can make good effects on three aspects- ecological environment, economy and society.

(1) The effects on ecological environment

Having a small volume and a little influence on the ecological environment, the ponds for gathering rainfall can not produce big effects on the ecological environment. While the reservoirs can usually produce some questions of the ecological environment such as inducing the earthquake, changing the climatic situation of the areas having the reservoirs, changing the runoff and sand's scour and deposition siltation of the rivers, changing the groundwater system and causing the changement of the biocoenose. Unlike the reservoirs, though the ponds for gathering rainfall can neither improve the regional climatic situation, nor ever the annual distribution of runoff and the periodic variation of annual runoff of the rivers, nor increase the amount of the groundwater resources, nor can bring some other beneficial ecological effects, yet compared with the building of the reservoirs, building the ponds for gathering rainfall in the regions of the upper reaches of the Huaihe River can bring some ecological effects on the following aspects:

① Preventing the climatic arid in the areas of the leeward slope around the reservoirs

The existing of the reservoirs can make the temperature of the surface of the reservoirs lower than that of the land in summer, can stabilize the atmospheric stratification and form the "low temperature effect" of the reservoirs, reduce the rainfall of the areas in the leeward slope around the reservoirs, so to make the climate arid. It is investigated that there

is a large area of cactus community on the upper reaches of the Baisha Reservoir, which is unsuitable for the climate type of the local regions and influenced by the arid climate caused by the existing of the reservoir. With the small volume and area, the ponds for gathering rainfall can not change the heating situation of the reservoir area, and so cannot make the climate of the reservoir area become arid by decreasing the rainfall.

② Preventing the deterioration of the water quality

The still water surroundings of the reservoirs can make the pollutant in the water be detained in the reservoirs and precipitate in the bottom of the water, and can form the phenomenon of layering water temperature. At present, the water in the reservoirs often drawn from the deep holes, the pollutant in the water of discharge has a high concentration and low temperature, thus can lead to the deterioration of the water quality and form the "cool injury", and cause the reduction of output of the crops and fish in the regions of lower reaches. According to the calculation, the large-scale reservoirs on the upper reaches of the Huaihe River play an obvious role in stabilizing the water temperature structure and preventing the influence of the "cool injury". With the shallow depth of the water and the short renewal cycle of water exchange, the ponds for gathering rainfall cannot form the phenomenon of the division of the elements of water quality, and there is no cold water layer at the bottom and cannot cause "cool injury" when irrigating the farmland with the water from the ponds. The ponds for gathering rainfall are often located on the top of the gully which is far away from the residential area and the industrial and mining enterprises, so there is few resources of pollution and the quality of water is quite good. So, by using the ponds for gathering rainfall to store water is a better way to protect the water quality of the water sources.

③ Be beneficial to the water and soil conservation

According to investigation, the area of water source of the upper reaches of the Huaihe River mainly distribute on the upper reaches' valley of each tributary, whose main topography is hilly land. For example, the drainage area of the upper part of the Baiguishan hydrometric station of the Shahe River is 2730km^2 , and the rate of water production is $1023000\text{m}^3/\text{km}^2 \cdot \text{y}$, the drainage area of upper part of the Ziluoshan hydrometric station of the Beiruhe River is 1800km^2 , the rate of water production is $282000\text{m}^3/\text{km}^2 \cdot \text{y}$. They are the two most important water production area of the upper reaches of the Huaihe River. Mainly, there are two types of the area of sand source: one is the upper reaches' drainage of each tributary, such as the upper drainage the Xiangcheng hydrometric station of the Beiruhe River, whose area is 485km^2 and erosive modulus is $396.6\text{t}/\text{km}^2 \cdot \text{y}$; the other kind is the river course below the dam of the reservoirs, such as the river course from the dam of the Baiguishan Reservoir of the Shahe River to the Luohe hydrometric station, its length is about 85km , its sand production is $16331000\text{t}/\text{y}$; and the river course from the dam of the Baisha Reservoir of the Yinghe River to the Yingqiao hydrometric station, its length is about 63km , its sand production is $136000\text{t}/\text{y}$. If the ponds for gathering rainfall

are built instead of building the reservoirs on the regions of the upper reaches, on the one hand, they can remove the area of sand source of the river course below the dam of the reservoirs and reduce the sand production of the river. On the other hand, they can hold back the water and the sand from the upper reaches, prevent the soil erosion, and can also reduce the sand amount of entering the reservoirs which are located the lower reaches, prolong the life of the reservoirs. At present, the sand deposit is so serious in some reservoirs on the upper reaches of the Huaihe River that the reservoirs can not play their role effectively. For instance, since the Baisha Reservoir was put into action, the sand deposit has been measured for four times, the results are that the amount of the sand deposit was 2390000m^3 from 1953 to 1959, 649000m^3 from 1960 to 1967, 551000m^3 from 1968 to 1979, 527000m^3 from 1980 to 1987. The total amount of the sand deposit is 32700000m^3 in the 35 years, 10700000m^3 beyond the reservoir volume of original plan for sand deposit (22000000m^3), which is equivalent to the loss of a medium-sized reservoir. Just for the notable function of conservating the water and soil, when many counties in the regions of the Huaihe River's upper reaches lay down the plans of conservating water and soil and zonalities of water conservancy, they all take the building of ponds for gathering rainfall in the gullies of the hilly land as one of the important measures of the conservation of water and soil.

(2) The effects on economy

The minor scale decides that the ponds for gathering rainfall cannot exert the multi-objective comprehensive role and bring large economic benefits for the local regions, as the reservoirs can. Now, most of the large-scale key water control projects are multi-objective. They have the functions of preventing flood, irrigation, generating electricity, navigation, providing water, aquaculture etc., bringing huge economic benefits, and they can even drive the economic development of the whole region. We can take the Nanwan Reservoir in the Shihe River as an example, it was put into effect in 1960, besides its role of preventing the flood effectively, ensuring the security of the main roads and the farmland and the towns in the lower reaches, it also brought great effects on irrigation, generating electricity, providing water for cities, fish culture, navigation and so on. Till now, the Nanwan Reservoir has developed the irrigation area of 1030000 Mu , of which 650000 Mu is the area of paddy field, and its annual electric energy production is $12540000\text{ kilowatt-hour}$, and the annual water amount for supplying Xinyang City is 16000000m^3 , and the water area of fishculture is 40000 Mu , and its navigable mileage is 67 km . According to the data calculated by the Water Conservancy Department of Henan Province towards the Nanwan Reservoir, the annual average income of preventing flood is $0.283\text{ billion Yuan}$, deducting the annual expenses $0.076\text{ billion yuan}$, and the net income is $0.206\text{ billion Yuan}$. And the total benefits in 30 years is 4.8 times of the total investment, with the fixed years of repaying the capital is 7.4 years.

Though the building of reservoirs can bring enormous profits, it can also bring

economic losses on some aspects, especially the losses of the lump-sum investment of some projects construction and submerged losses. From the consideration of this aspect, compared with the building of reservoirs, the building of the ponds for gathering rainfall has the following advantages on the economic benefits:

① The smaller amount of the lump-sum investment of the project construction

The project construction of building reservoirs costs a huge amount of investment. According to the price in 1950s, the amount of the lump-sum investment of the regional large-scale reservoir can reach more than 10 million Yuan. The local financial organ can hardly pay such tremendous investments and only depend on the state investment. It needs smaller amount of investment to build a pond for gathering rainfall, just thousands of Yuan is enough, and the local peasants can raise them by themselves. In addition, the limited time for building ponds for gathering rainfall is short, and people can use the slack season for building without effecting their farmwork. Lower level of technique is required, the building of ponds can easily be extended in the lackware areas on the upper reaches of Huaihe River.

② The smaller submerged losses

The water deposit of the reservoirs can cause huge submerged losses including the submerged losses of the cultivated land and the compensation of the emigrants. Most of the reservoirs are built on the favourable hilly land. After depositing water, they can submerge a large area of plants, which distributed along the river. With the flat ground, thick soil layer, and the favourable irrigation situation, these areas are the local Golden Land, and are cultivated as fertile farmlands and provided a large number of crops and vegetables for the local people. The submergence of the cultivated land caused by the reservoirs make the cultivated land became much less, and certainly aggravate the contradiction between the local population and the cultivated land. For instance, the Baiguishan Reservoir submerged 79500Mu cultivated land. The building of a reservoir needs moving a large number of people living in reservoir area. For example, the emigrants of the Baiguishan Reservoir is 37200 people. The movement of large population in the submerged area also needs huge amount of compensation for re-setting down. Especially, at present when the economy has been developed into a high level, the moving of the population requires the exploiting kind of emigrants and has a high requirement for the condition of housing, living and employing, and the expenses are much higher. Usually situated on the top of hillside with the steep slope, barren land and far away from the residential place, basically the ponds for gathering rainfall need not occupy the cultivated area and need not emigrants, and can save lots of investments.

③ Promoting the economic development in the countryside

Though the function of the ponds for gathering rainfall is limited by its small-sized scale, and can not be used multi-objectively as reservoirs, it can give full play to the comprehensive benefits, such as development of irrigation, fish and duck culture, and other

diversification. Because of the high location of the pond for gathering rainfall, there is no need to draw water and just the gravity irrigating is enough when irrigation the farmland. Because the water depth of the ponds for gathering rainfall is shallow, there is no cool water at the bottom, and the pollution of water quality is slight, it is favourable for the fish's growth and for the quality improvement of the products of fish and ducks, and for the fishery. One point warrants our mention is that most of the ponds for gathering rainfall are situated in the backward countryside of the hilly land area, if their comprehensive functions are brought into full play, obvious economic benefits can be got and it is of great significance to promote the development of the local rural economy, and to make the local peasants get rid of the poverty and become rich. Presently, the comprehensive functions of the ponds for gathering rainfall have not been fully utilized, and their developing potential is great, so, later we should enhance the work of developing their potential to the full.

(3) The effects on the society

Multi-objective social effects can be got by building reservoirs, of which the most important is the effect of preventing flood, which beyond the measurement of economic index. In addition, the reservoirs can also promote the development of the tourism on the reservoir areas. Having a small volume, the ponds for gathering rainfall can not play such great function in adjusting flood as reservoirs can. But, the building of ponds for gathering rainfall can get the following social effects:

① Avoiding the unfavourable function of reservoirs in preventing flood

Although the reservoir can adjust flood and effectively prevent flood disaster, it still has two unfavourable functions in preventing flood. Firstly, it can increase the flood peak flow when come across a catastrophic flood. When a smaller flood happens, depending on its large volume, reservoir can retain the flood and have an obvious effects in reducing the flood. But when a catastrophic flood like the "75. 8" flood happened, reservoir cannot retain the flood any more and it should discharge the flood all-out in order to ensure the safety of the dam. Then, the peak flood flow of the discharge is certainly more than that of the natural river course under the condition of without the reservoir, owing to the retaining water retained in the early stage of the flood. If the accident of dam collapse happens, the flow of peak flood will be much more. Under these circumstances, instead of reducing peak flood, reservoir can increase the flow of peak flood, and may lead to more serious losses and damages. The cases of the Banqiao Reservoir and other reservoir's situation in the period of the "75. 8" catastrophic flood fully explained this point. Secondly, it changes the flood disaster into waterlogging disaster. In 1950s, lots of reservoirs and detention basins were built in the upper reaches of the Haihe River, and the situation of "3 times flood in 5 years" had been changed. However, plenty of flood water has been retained in the low-lying land of upper reaches by reservoirs and detention basins, and could not flow down for a long time, so the serious water logging disaster has been formed. After the flood, originally the water could be drained away in 3-5 days, but now it needs 10-15 days. The

losses of waterlogging decreased the effects of reservoirs on some extent, and this part of losses used to be neglected in the analyses of reservoir effects, thus the effects of reservoir were exaggerated. If the ponds for gathering rainfall are built for retaining water, above-mentioned unfavourable influence can not come into being. Though the volume of the ponds is small, and the effect of retaining flood is not quite good, the pond's requirement for the topography is not as strict as reservoirs, and the ponds can be built in a large number. Notable effects of preventing flood can be got by the cooperative functions of lots of ponds for gathering rainfall.

② Avoiding disputes of using the farmland

Large area of cultivated land are occupied for building reservoirs, and part of the economic benefits of reservoirs are returned to the ownership units, the original units who have the using right of the farmland will surely raise the claims of obtaining some benefits to compensate the economic loss caused by the lossing of the farmland, so inevitably some disputes of using the farmland will arise. The dispute in Suyahu Reservoir is quite striking. The local people tried to get the using right of the low-lying land beside the dam and the road entrance in the south of the dam for developing fishculture and carrying out agricultural trade. This makes a lot of difficulties in the normal reservoir's management work of the Administrative Bureau of the Reservoir. The ownership of the ponds for gathering rainfall and the using right of the farmland occupied by the ponds belong to the same people or unit, who enjoy the profits alone, so there will not be the disputes of using farmland.

③ Avoiding the social problems caused by emigration

No reservoir can be built without emigrant, which can not only cause the heavy economic pressure, but also can have great influence on the population of immigration and the immigrant areas. Chinese peasants have a deep-rooted traditional thought, that is, it is hard to leave one's native land. If forced to move their residences, they will have an idea of living in a strange place and form the serious psychological pressure, and can not adapt to the new living circumstances for a long period of time. It is even difficult for them to get along well with the original citizens, and disputes often take place between the old and the new residents. The emigration not only can bring the economic and environmental pressure to the immigrated areas, but also can influence the economic development and the living standard of the local people, so the original residents have an un-welcome attitude towards the immigrant. Such immigration problems and some other social problems are not exist in building the ponds for gathering rainfall.

④ Preventing the spread of disease

The existing of the reservoirs can lead to the spread and prevalence of many kinds of diseases, especially the diseases whose pathogen or vector live in the water of swamps. Moreover, the immigration can spread some diseases. After the retaining water of some reservoirs in the upper reaches of the Huaihe River, the incidence of malaria increased obviously in the reservoir areas. While, with the small area and high location, the ponds

for gathering rainfall can not form large area of swamps, and being far away from the residential places and no emigration is needed, so the ponds for gathering rainfall can not arouse the spread and prevalence of the diseases and do little harm to people's health.

3. Conclusions

Because of its small volume and high position, compared with reservoirs, the ponds for gathering rainfall have some favourable effects on ecology, economy and society, and it can be the ideal coordinated project of the reservoir in the areas of the upper reaches of the Huaihe River to avoid some harmful effects caused by building reservoir. At present, many ponds for gathering rainfall have been built in the areas, and great effects have been got on the irrigation of farmland, the prevention of flood disaster, the conservation of the water and soil and so on. However, these ponds are built by the local peasants themselves just for the purpose of irrigating their farmland, so they are of low quality, and the leakage is serious, and the rate of retaining water is only about 50%. Therefore, the ponds for gathering rainfall haven't played their full functions and they are not used comprehensively and their effects haven't got into full play. In the work ahead of developing the ponds for gathering rainfall, we should pay attention to the following questions: Firstly, we should make the rational plan and devote major efforts to developing it so to give full play to its function in preventing the flood and waterlogging disaster; Secondly, we should take pains to construct and try to improve the quality of the projects and promote the efficiency of the water storage of the ponds for gathering rainfall; Thirdly, we should devote major efforts to developing the comprehensive utilization of the ponds for gathering rainfall and doing well in the diversified economy and the courses of farmland irrigation, to build good ecological farming model of land and ponds comprehensive utilization, and to get better economic effects.

THE PRESENT STATUS AND FUTURE PROSPECTS OF RAINWATER CATCHMENT SYSTEMS IN TAIWAN

S.C. Chu*, K.F. Andrew Lo** and C.H. Liaw*

ABSTRACT

Since the 5th International Conference on Rainwater Catchment Systems being held in Taiwan in 1991, the benefits of rainwater catchment systems have been recognized in Taiwan. In recent years, with the endorsement of the International Rainwater Catchment Systems Association headed by Prof. Yu-Si Fok, rainwater catchment systems have been widely utilized by users, decision makers and researchers in Taiwan. Rainwater catchment technology has been studied and utilized for years in rural areas, in agriculture and in industries. The Taiwan government has begun the promotion of rainwater catchment in towns and cities. The ultimate goal is to be able to integrate efforts from both the public and private sectors in order to efficiently and economically utilize the rainwater resource to alleviate the ever-increasing drought problem in Taiwan.

INTRODUCTION

The mean annual rainfall in Taiwan is about 2,500 mm. It is a water-rich country. Yet, the annual available water resource per capita is very limited. This problem is probably due to high population density and uneven spatial and temporal rainfall distribution that creates extreme flood and drought conditions. The absence of rainfall during winter and spring seasons often results in frequent drought and severe water shortage problem.

According to the statistic data provided by the Ministry of Economic Affairs, the total annual surface runoff in Taiwan is about 67.5 billion cubic meters. About 78 percent of the total runoff occurs during the rainy seasons (May to October) and only about 22 percent during the dry seasons (November to April). Rainfall derives primarily from convective storms with the typhoon passage. Therefore, drought even occurs during rainy seasons in years with fewer number of typhoons or with continual "dry" typhoons

* Associate Professor, Dept. of River & Harbor Engineering, National Taiwan Ocean University, Keelung, Taiwan 20224

** Professor, Dept. of Natural Resources, Chinese Culture University, Taipei, Taiwan 11114

such as the droughts in 1974, 1980 and 1982. The water shortage problem is most pronounced during dry seasons. It affects the water demand that serves many different purposes. There is, obviously, an urgent need to seek immediate solutions to the water shortage problem in Taiwan. However, faced with the extreme hardship in new water resource development, the one of feasible alternatives is to intensify efforts in managing the available water resources to overcome the supply shortage.

The Department of Water Resources, Ministry of Economic Affairs, and other related government agencies have developed a water conservation program that includes five strategies and twenty-two action plans. They are designed to enhance efficiency management, provide public incentives, modify legislations, rationalize water price and educate public awareness. This program has also been included as one of the twelve national development projects and is officially named "Water Resource Development and Management Enhancement Project". Rainwater catchment technology is considered as one of the water conservation practices and an important water resource development alternative. The Department of Water Resources has recently drafted two incentive proposals. The first proposal aims at promoting research in water-saving devices and technology and rainwater catchment system design technology. The second proposal is to encourage construction and utilization of rainwater catchment systems in areas short of water supply.

RAINWATER CATCHMENT SYSTEMS

Generally speaking, all forms of water resource development can be tied to rainwater since the water source is derived originally from rainfall. The use of stored rainwater discussed here focuses only on the utilization of rainwater caught from the sky by individuals such as families, communities, industries or farms. This method is often regarded both as an ancient and a re-discovered water supply technology. It is old because it was first used in the Roman Empire. The collected rainwater was being used from extravagant villas to domestic water for the entire township. In the last twenty years, the practice of rainwater catchment has been re-emphasized in many parts of the world. Many common terminologies have emerged in the literature that included: rainwater use, rainwater resource, rainwater catchment, rainwater storage, runoff farming, rain-harvesting agriculture, and urban stormwater use. This indicates that rainwater use will be an important trend in the development of water resources in the next century.

Rainwater use does not require a lot of energy and creates little pollution. It also does not invoke water conflicts. Therefore, it is a practical and economical yet small-scale technology. However, it is capable of imposing large-scale environmental and ecological benefits, especially in semi-arid and sub-humid areas lacking adequate water supply. The application and utilization of stored rainwater can be multi-faceted. It has been

used as supplement of domestic water supply for non-potable purposes. It has been widespread used for all sorts of purposes in remote islands lacking fresh water supply. It has also been traditionally used in agriculture in water conservation terraces, rainwater catchment irrigation and rain-harvesting agriculture. In urban areas, rainwater has been commonly used for sanitation purposes, fire protection, greenery and landscaping, water retention, and groundwater recharge. The use of rainwater can be grouped into two major categories, namely temporary and permanent. Possible forms of rainwater use are shown in Figure 1.

PRESENT STATUS

There are all sorts of rainwater catchment systems. When considering only its usage, there are two main types: for public water supply purposes and for agricultural purposes. The public water supply usage involves collection, storage, and treatment. The agricultural usage includes collection, storage, and distribution. Based on its collection methods, there are three kinds of rainwater catchment systems, namely roof-top catchment, ground surface catchment, and dam catchment (underground reservoir). There are other types of rainwater catchment systems designed to fit users' cultural, social and economic needs.

Various types of rainwater catchment systems have been used in Taiwan:

(A) Rural Rainwater Catchment Systems

Rainwater catchment systems serving the general public are usually large in size and are built by the government. They are constructed under strict engineering guidelines. One example of such system is discussed here.

Penghu Archipelago is located west of the Taiwan and includes 64 islands. Total area is about 126 km². The mean annual rainfall on the islands is about 1,000 mm. The evaporation is about 1,800 mm. Therefore, the water resources on the Penghu Archipelago are always in short supply. The surface water collected by reservoirs and groundwater pumped from deep wells are the major sources of water supply. During the dry seasons, chances of rainfall is very slim or close to none. The public water supply relies entirely on the groundwater. There are altogether five reservoirs in Penghu with an effective storage capacity of about 2.7 million m³. Among them, Cheng-kung reservoir is the largest with a capacity of 1.04 million m³.

Usually there is no streamflow flowing into the reservoir. It relies entirely on the 3.04 km² watershed area for rainwater collection. Penghu lacks a perennial river and sufficient hydrologic information. At the beginning, during the planning phase of the reservoir, the predicted reservoir inflow was estimated based on daily rainfall data, an

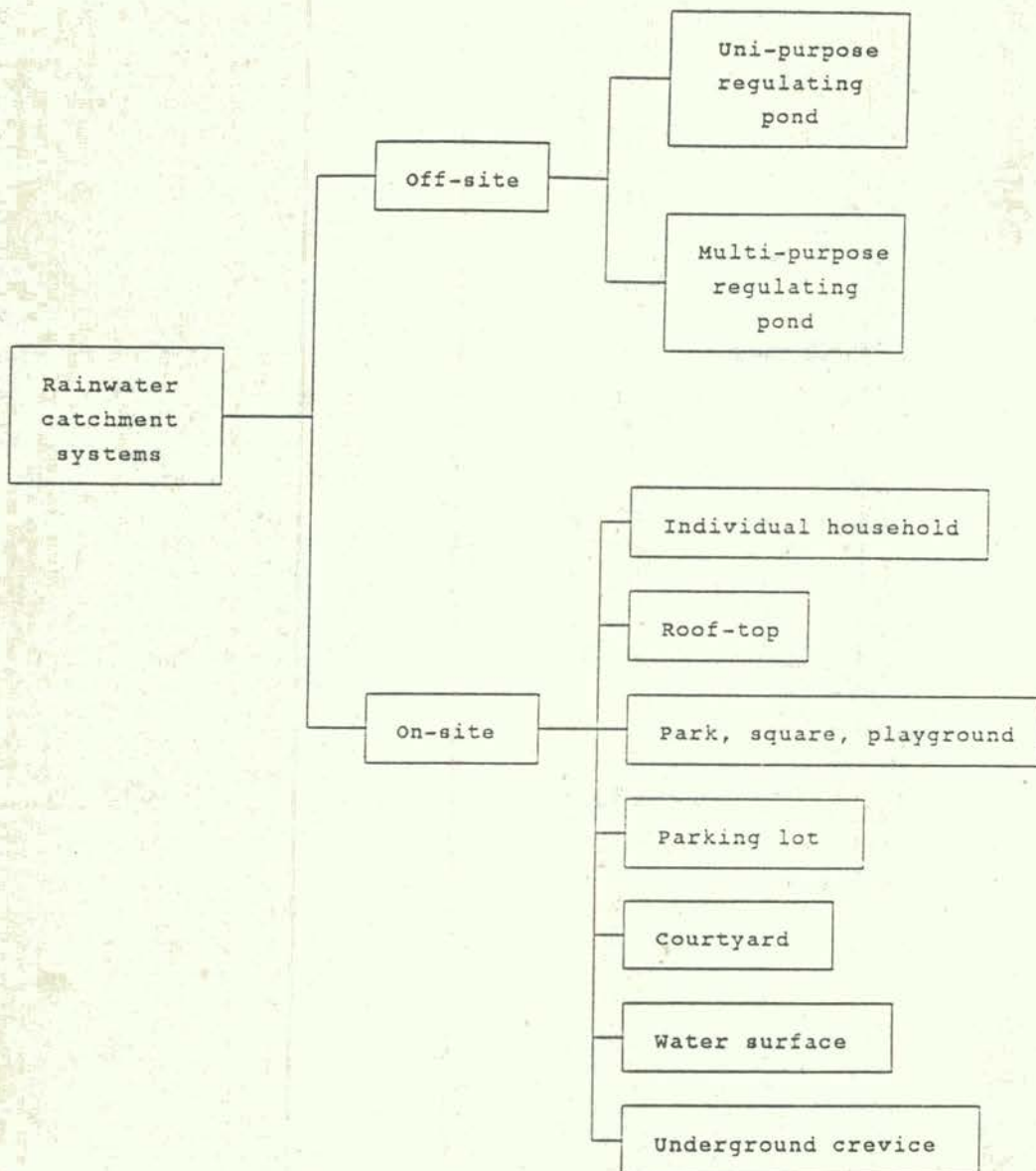


Figure 1. Different forms of rainwater catchment.

assumed runoff coefficient and the rational formula. It was realized after the completion of the reservoir that the runoff coefficient was over-rated. In other words, the reservoir cannot satisfy the design water demand.

A time and rain dependent runoff coefficient was later used to adjust for the constant and over-estimated coefficient. At the same time the Taiwan of Water Conservancy Bureau in cooperation with the Council of Agriculture also initiated a project aimed at increasing the water supply efficiency of this reservoir. Diversion ditches were built to convey rainwater from the nearby watersheds. This extended the reservoir watershed area by another 1.86 km² and increased the annual water supply by another 300,000 m³. Since the completion of the diversion ditches, the operation of the Cheng-kung reservoir has greatly improved and the water shortage problem in Penghu is greatly lessened.

(B) Agricultural Rainwater Catchment Systems

Generally speaking, the early rainwater catchment systems used for crop irrigation were mostly privately built. They were used only to satisfy irrigation during drought condition and pesticide spraying. They were constructed according to the owners' wishes and experience. Usually, they cannot fulfill future water demand. The government recognizes its usefulness only after the water problem becoming more serious and starts to construct more rainwater catchment systems. The following examples illustrate the rainwater catchment systems use for crop irrigation:

1. Large areas of undulating tablelands are commonly found in the northern part of Taiwan within the Taoyuan and Hsinchu Counties. Their elevation range from sea level to about 240m. The average slope steepness is about 1 percent. The prevalent soil in this area is the clayey soil with poor drainage. Therefore, this area is quite suitable for rainwater catchment systems development. Because rainfall was the only source for supplying irrigation in the old days, thousands of farm ponds were built and used by local farmers for a long time. Many ponds are small in size, privately owned, and scattered throughout the whole district. Farmers often have difficulty fulfilling their irrigation needs with rainwater catchment alone. Therefore, in 1964, a multi-purpose reservoir was built at Shihmen. Its completion and operation has greatly alleviated the water shortage problem in this area. Shihmen reservoir is designed to deliver 48 to 50 percent of the total irrigation water needs. The remaining portion has to be supplemented by rainfall, return irrigation water and farm ponds. Since the main source of water for farm ponds is rainfall, the irrigation water supply is still unreliable. Water shortage problem often occurs. However, several remedial steps have been installed recently to improve the situation. The storage capacity has been increased to between 21,200 m³ and 643,000 m³. They are all managed and operated by the local Irrigation Associations. They are operated like a series of

reservoirs. The only difference is all the farm ponds have to maximize water storage for drought periods use. The Irrigation Associations use the linear programming theory to estimate the optimal water release. These steps have been proven successful in solving the water shortage problem in these areas.

2. The hilly areas of southwestern Taiwan is dominated by mudstone soils. Rivers and streams are short and fast. They are completely dry during dry seasons. Frequent water shortage has prompted serious constraints on farmers who rely solely on rainwater for their crop production. The main reasons why this area lacks sufficient water supply are:
 - (a) The annual average rainfall is about 2,100 mm in this region. Though it is considered plentiful, it is not well distributed in time and space. More than 90 percent of the rain is concentrated during summer and typhoon seasons.
 - (b) The soil erosion problem is very serious in this region. The average soil depth is less than 50 cm. The soil water retention and holding capacity is very low. Therefore, available water supply is rather limited.
 - (c) In most mudstone slopeland, gully formation is quite common and steep. Rainwater cannot percolate and recharge into groundwater.

Studies have been conducted based on the hydrological and meteorological conditions, land use pattern, and current rainwater catchment systems distribution and utilization status at several towns and villages. These information were used to simulate agricultural water use and to determine the optimum rainwater catchment system design. Results obtained were compared with on-site survey to facilitate further extension for agricultural usage.

The field survey results also indicate that farm ponds are an important and a special feature of rainwater catchment systems in the mudstone areas of the southwestern part of Taiwan. Besides storing rainwater during rainy seasons for supplying dry seasons need, farm ponds can also reduce surface soil removal, prevent landslides, and stabilize slopeland. The silted up farm ponds can be later put to more effective use such as growing crops. The farm ponds, aside from providing irrigation water supply, can be diversified for animal husbandry, aquaculture, and touristic development. With the year round adequate supply of water, more high value-added crops can be grown which will greatly increase opportunity of agricultural development and the living standard of the farmers in these areas. Therefore, the rainwater catchment system is an essential alternative resource in the mudstone areas and is able to provide the much needed solution to the water shortage problems.

(C) Industrial Rainwater Catchment Systems

The recent economic development in Taiwan has increased the domestic and industrial water demand. Because of natural environment constraints and public environmental awareness, new water sources are extremely difficult to develop. In order to fulfill higher water demand, the only resort is to find new water sources.

Yu-Chia is a new industrial park to be developed off-shore on the western part of Taiwan. A feasibility study has been initiated in 1993 to assess the use of rainwater catchment systems to alleviate the water supply problems encountered during the industrial development process. Preliminary results indicate that the most suitable methods to collect rainwater are by roof-top and ground surface methods. Rainfall in this area is concentrated between the months of May to September. Therefore, rainfall catchment systems should be very appropriate for alleviating the problem of uneven rainfall distribution and the best substitution for supplying water for this development project.

FUTURE PROSPECT

Rainwater catchment is a feasible alternative water source. It is both an ancient and a re-discovered water supply technology. In the last twenty years, its fast pace of development has led to the establishment of the International Rainwater Catchment Systems Association. In many countries, rainwater catchment systems collect rainwater on roof-top and ground surface, and are useful in supplementing domestic water supply, fire-protection, and reducing peak runoff in urban areas. Both the design and implementation will be critical in the near future. The Department of Water Resources, Ministry of Economic Affairs has already established several incentive programs to speed up the promotion of rainwater catchment systems applications in Taiwan.

Rainwater use is the future trend of water resources development. Although the scale is small, its economical and practical technology can impose large environmental and ecological benefits. These effects are most significant in semi-arid and water deficient sub-humid areas. The application of rainwater catchment is quite diverse. In urban areas, it can be used for sanitation, fire-fighting, reserve water supply, greenery, landscaping, and groundwater recharge. Rainwater usage requires less energy and produces little pollution. Therefore, it will be the new water resources for the 21st century.

In recent years, the occurrence of frequent droughts, the increase in commercial and industrial activities, and the impact of joining the General Agreement on Tariff and

Trade (GATT) would substantially modify the future water policy. The water storage would undergo drastic changes. Therefore, the planning, construction and promotion of rainwater catchment systems as a renewed water source needs to be strengthened to meet the future demand.

In addition, the Architecture Research Institute, Ministry of Interior has studied and successfully developed the technology of recycling treated sewage water system. This system, if coupled with other water conservation devices, would be very effective in solving the water shortage problem. Hopefully, the necessary installation guidelines may be developed soon to allow immediate implementation by architects and constructors. Rainwater catchment systems can either work together with the recycling system to supplement insufficient public water or provide as one of the available water sources for the system. Both are being considered as important water-saving schemes.

RECOMMENDATIONS

The following suggestions should be useful for the application of rainwater catchment systems in Taiwan:

1. Rainwater catchment systems should be developed on a long-term basis and should include environment conservation as one of the design objectives.
2. Rainwater catchment is an easily available and a high quality water resource. The system uses roof-tops to collect rainwater that minimizes land use and creates no water conflicts. It should be recommended and promoted for widespread non-potable use.
3. Though this alternative water source may reduce the revenues of the public water supply system, the government should introduce new legislations to provide necessary incentives to improve efficient utilization of this low-risk water resource.
4. The government should take the lead and award local governments, schools, communities, industries and farmers that utilize rainwater in areas lacking adequate water-supply. Government sponsored campaigns and educational programs are useful tools to change the public attitude towards rainwater usage and to raise public awareness about rainwater resource preservation.
5. The government should encourage the construction of dual water supply system in large communities, townships, highrise buildings and industrial plants.
6. In accordance with agriculture policy, it is recommended to develop slope dryland irrigation in mudstone area using rainwater catchment systems.

REFERENCES

1. Chu, S.C. and Fok, Y.S. 1991. Multi-Objective Rainwater Cistern Systems. Proceedings of the 5th International Conference on Rainwater Cistern Systems. Keelung, Taiwan. 448-455.
2. Chu, S.C. and Lo, K.F. 1992. Keelung Isle Rainwater Catchment Systems: A Case Study. Proceedings of the 1992 Regional Conference, International Rainwater Systems Association. Kyoto, Japan. 781-792.
3. Chu, S.C. and Liaw, C.H. 1993. Study on Agriculture Rainwater Cistern Systems of Mudstone Areas in Southern Taiwan. Proceedings of the 6th International Conference on Rainwater Catchment Systems. Nairobi, Kenya. 457-462.
4. Fok, Y.S. 1994. Methods for Rainwater Catchment Systems Development in Taiwan. Taiwan Water Conservancy. 42(3):5-8.

RAINWATER HARVESTING PROJECT
FOR
BOUNAVISTA

LAKSHMAN WELIKALA

ABSTRACT

This paper describes a Rainwater harvesting Project Undertaken in Sri Lanka. Rainwater from roofcover is not a common practise in this country. This is the first project of this nature that has been designed to overcome the Water shortages during droughts. This project has many benefits in helping the social upliftment programmes undertaken by the institution together with helping the poor community with their Water requirements. The natural landscape and the resources available at site are utilized to its maximum advantage. The World Council of Churches in United Kingdom has been most gracious by coming forward to fund the project.

RAINWATER HARVESTING PROJECT BOUNAVISTA - GALLE - SRI LANKA

- 01 - INTRODUCTION :- The history of Sri Lanka tells us that we have been pioneers of conserving Rainwater mainly for the purpose of agriculture since 500 A.D. These systems are still prevailing which proves that Rainwater from large and small catchments could be successfully collected especially in the Dry Zone where the rainfall is seasonal. Rice being our staple diet the economy of the country depended on rainwater, and hence the ancient rulers gave prime importance to its conservation. Water collected in reservoirs became the nucleus of village life giving rise to a system of culture depending on the cycle of rainfall webbed with agriculture and religion.
- 02 - BOUNAVISTA HILL :- This is a rocky hill in the Southern coast of Sri Lanka, famous for its historical background, it still contains the natural and rare herbs and plants surrounded by a beautiful beach. It rises to about 80m above Sea level and covers a land area of 300 Hectares.
- 03 - SCARCITY OF WATER :- Ground water which was readily available in the past is diminishing very fast giving rise to frequent water shortages. About 90 families living on this depend on well water as the pipe born water cannot be supplied due to its high elevation.
- 04 - REASONS FOR WATER SHORTAGE :- Quarrying of Rock for metal industries and clearing of shrubs jungle by villages for firewood and settlements have contributed largely to diminishing of the natural underground springs. A drought period of more than two weeks brings many hardships to villagers living on top of this hill. These dry periods occur annually and is on the increase.
- 05 - BUILDING COMPLEX :- The Bounavista Building complex is situated on the peak of the hill constructed almost two centuries ago is owned by the Anglican Church of Sri Lanka. This centre was used for a girls orphanage in the past and has accommodation facilities for about one hundred hostellers. There is also 1 1/2 hectares of very fertile land around this building.
- 06 - PRESENT PROJECTS :-The present authorities are utilizing this complex for social upliftment programmes mainly for the poor villagers living on this Hill.
- They are :-
- (a) Creche for poor children
 - (b) seminars and workshop for youths.
 - (c) Distribution of nutrients to lactating mothers.
 - (d) Training to women on skills.

Water shortage during the periods which occur annually greatly hamper these ongoing projects and brings all activities to a standstill.

07 - PRESENT WATER SOURCES FOR THE COMPLEX :- Presently there are two sources of water for the building complex,

- (a) Hand dug well
- (b) Tube well

(a) THE HAND DUG WELL : The present hand dug well is about 10m deep and has reached the rock bottom. About 400 gallons of water can be supplied daily on normal period. But it cannot cater at times of seminars where 80 to 100 Youth occupy premises for 2 to 3 days. during the months of the year which lasts for 3 to 4 weeks, the well water diminishes making the institution helplessly dry.

(b) THE TUBE WELLS : Two years ago two tube wells were dug to overcome this crisis but water was found only at 78m below the ground level.

During the normal period the water supply is satisfactory and a source of great service to the village. But during the dry periods the ground water level goes down giving few Litres of water a day and that too is not potable due to salinity.

08 - RAINWATER HARVESTING :- The only other source of water available at the site being, the rainwater that falls during the rainy season, this project had to be the only alternative to overcome the water crisis during the dry months of the year.

09 - Factors Considered :- An initial study of the location, weather pattern and area of roof cover indicated that sufficient Rainwater could be collected from the roof area to enable the institute to tide over the drought period and also have excess water to undertake additional income generating projects.

09.1 Water Requirement :

Peak requirement of water for the Institutions.

At times of Seminars per month - 136,000 Liters.

Normal monthly requirements per month - 68,000 Liters

Average Requirement per month - 102,000 Liters

Assume 50% could be supplied by ground water Sources presently available.

balance Required - 5 1 0 0 0
Liters/month

09.2 Annual Rain fall :

Long Term Average for the District of Galle - 2465 mm

Last Ten average - 2000 mm

Last Drought Year of 1992 - 1450 mm

Assumption : Drought Year 1992 Taken for calculation

Average Monthly Rain fall - 120.75 mm

09.3 ROOF COVER :

Total Roof cover	-	1300 m ²
Total Yield - Total Roofcover X		
Average monthly Rainfall	-	1300 M ² X 120.75 m
	=	157,000 Litters
Allow 30% for losses for wastage due to evaporation, absorbtion and overflow from gutters	-	47100 Litters
Balance	-	109900 Litters
Therefore 50% of Roofcover is sufficient	-	54950 Litters
Maximum monthly rainfall observed during last 10 years	-	300 mm
Maximum Rainfall that could be harvested during a month	-	1300/2 X 300 X 70/100
	=	136500 Litters

10 - CONSTRUCTION OF STORAGE TANK :- Construction of a tank is very expensive therefore it was decided limit it to 32000 litters and divert the balance to a Reserve Tank, RCC storage tank is a fully sealed concrete tank which will prevent any forms of pollution and mosquito breeding.

10.1 Storage Tank : The storage tank which is constructed with R C concrete will be fully sealed. The overflow of this tank is diverted to the Reserve tank. It will have the following installation.

- (i) Waste Water Plug
- (ii) Supply line to a tap stand
- (iii) Electric water pump
- (iv) Water gauge

10.2 Collecting Systems : The collecting of Rainwater is done in the following manner

10.3 P.V.C. gutters and downpipes : P.V.C. gutters and downpipes have been installed to divert the water to collecting chambers.

10.4 Collecting chamber : The roof water coming from the P.V.C. gutter system will first go to two collecting chambers which are above ground level but sealed.

10.5 Control chamber : The water from the two collecting chambers will be diverted to a control chamber which will allow the initial flow of foul water to be drained away from the storage system. This will have to be done manually by releasing the out flow valve. Once the valve is closed the water will be diverted to the storage tank of capacity 31500 Litters.

10.6 Reserve Tank : A natural pool has been converted to a reserve tank and has a capacity of 135000 Litters of water.

The disadvantages of the Reserve tank is that it is an open tank which will be subjected to Mosquito breeding and evaporation. The Mosquito breeding could be prevented by fish breeding and the evaporation will have to be given due consideration after monitoring the amount of losses.

10.7 Diversion : All diversions are done by 225 mm reinforced concrete cylindrical pipes, buried underground wherever necessary to maintain natural landscape.

10.8 Manholes : Several manholes are provided for clearing of any obstructions on this line.

10.9 Electric Pump : A 25 mm Ø Electric pump is installed on the storage tank to pump the water to the main overhead tank that supplies water to the institute.

11 - Maintenance :- the maintenance is mainly confined to clearing to the PVC gutters on roof. A wire mesh is provided at each down pipe point to prevent any dead leaves or debris coming from the roofs. As this will tend to clog the water at the gutter level manual inspection of gutters before the rainy seasons will be very important.

12 - Operations :- Operation is also confined to

(1) Switching on the electric pump to full the overhead tank.

(2) Draining the initial flow of the influx.

This has to be done when the rain comes after a dry period. Once the rainy season commences and the roof is clear this need not be repeated for every rain. This is done by operating a valve at the control chamber.

13 - Additional Community benefits :- Further to ongoing projects the following additional projects could be taken for the institution.

13.1 Cultivation : Mushrooms and Vegetables could be cultivated as there is a cultivable land of 1 1/2 Hectares around this building.

13.2 Planting fruits such as Papaw, Bananas and Pineapple grow very well due to its fertile soil. These items could be easily marketed to the tourist hotels in the vicinity.

13.3 Construction of a Herbarium : The Hill itself is very popular for its rare species of plant life and medicinal herbs. A herbarium will greatly benefit the student population in the Galle District in the study of Botany and promotion of preservation of the environment and nature.

13.4 Animal Husbandry : Such as poultry and farming could commence as sufficient water is available for its upkeep.

14 - These additional projects will not only bring economic benefits to the Institution but will greatly help the youths of the poor villagers in training in various skills, farming and agriculture for their future survival and sustenance.

15 - IMPLEMENTATION OF STAGE 11 :-

The water so conserved could be mainly used for, washing, bathing, and agriculture. But at times of severe drought, water may be necessary to be used for cooking and drinking purposes too. Therefore a simple filtration system is designed to make the water potable.

15.1 FILTRATION SYSTEM : This system will consists of two chambers. The first chamber will be filled with sand to filter all impurities and the second chamber could be used for chlorination. Chlorination will have to be done Manually.

16 - HARVESTING THE WIND ENERGY :- The project being situated on top of the hill has sufficient wind that could be harvested to operate a Wind - mill. A wind mill connected to a small manual pump near the Reserve tank, could be utilized to pump the water from the reserve tank to the additional overhead tank which feeds the system saving on electricity.

17 - FRESH WATER FISH BREEDING :- Another project that could be successfully commence is breeding of fresh water fish in the Reserve tank. this tank which has an open surface easily used for fresh water fish breeding for consumption. Fresh water fish such as Thalapi is used successfully to counter mosquito breeding as they eat the eggs. The fish too is used for human consumption.

18 - COST OF CONSTRUCTION :- The cost of construction of the project which is done in two stages is as follows :

Stage 1 : Installation of PVC gutters, down pipes, Reinforced concrete water tank and Reserve tank with diversion line and chamber is in the region of \$ 10,000 US Dollars. The necessary funds for this stage. Provided by the World Council of Churches in United Kingdom.

Stage 11 : Installation of a wind mill and purification system
- \$2000 (US Dollars) (Awaiting for a funding agent)

19 - The additional agricultural projects will enable to recover the investment within a period of ten to fifteen years. The social benefits derived by training youths on self employment is a service to the poor, and deserving villagers. The whole project is very practical and feasible as the system is based mostly on gravity. The construction is done using P.V.C. products and concrete which is durable and long lasting with very little burdens on overheads and maintenance.

This may be the first such project of this magnitude that is experimented in Sri Lanka. Rainwater from Roof cover is said to be harvested in the dry Zone of Sri Lanka where water is scarce. But it is not carried out scientifically or systematically. The success of this project will have to be monitored for few seasons ahead. It could certainly help to propagate the Rainwater Harvesting for household by utilizing it as a model project.

ANALYSIS OF ECONOMIC BENEFIT GENERATED DUE TO GROUNDWATER

RECHARGE BY INTERCEPTING RAINWATER IN NORTH CHINA

Yan Zhenyuan*

Groundwater recharge by intercepting rainfall runoff is an effective way in utilizing rainwater. The technique involved is normally referred to as groundwater recharge technique or groundwater recharge project.

In recent years, groundwater recharge projects have been established in North China by a big margin, included are Sihe recharge project in Yanzhou (33,400ha) and Wenhe recharge project in Ningyang (20,000ha) of Shandong Province. According to preliminary statistics, annual amount fed in average year by various recharge projects totalled 600 to 700 million cubic meters, around 10% of the total amount of groundwater utilized in average year of the province.

1. Background

In the 1950s and 1960s the focus of water resource exploitation and utilization was surface water in North China. Meanwhile a great many river causes and reservoirs were built in combination with flood control, water diversion projects and pumping stations were developed, and various types of irrigation districts were set up to expand irrigated area. However, in the early 1970s, the occurrence of successive water deficient years in North China led to substantial drop of runoff volume and irrigation was seriously affected. Therefore, groundwater exploitation became the focus, many motor-pumped wells and deep wells were dug to extract groundwater for agriculture related drought-resistance and water source for urban use. Such unplanned and uncontrolled groundwater extraction activities led to the imbalanced extraction and replenishment in a short period of time. Many funnel districts were formed as a result of groundwater mining. Groundwater depletion even occurred in some places where water was unavailable, both industrial and agricultural production was seriously affected and various eco-environmental issues caused. Then, people gradually became aware that groundwater was not inexhaustible in supply and always available for use, and groundwater source should be fed if they were used substantially. As vast amount of rainfall runoff was discharged during flood season, groundwater reservoir was taken as an ideal option for surface runoff storage. This is a low-cost and high-benefit way, and thus groundwater recharge projects emerged as the times required in North China.

2. Conditions

* Shandong Hydraulic Engineering Junior College
117 Daizong Street, Tai'an 271000, Shandong, CHINA

At least two conditions are necessary in building groundwater recharge projects.

2.1 Geological and hydrogeological conditions: They are the primary conditions for recharge project and should satisfy demands for surface water infiltration and groundwater storage in spreading basins. Specifically speaking, superficial layer and aquifer should have strong permeability, and perfect hydraulic connections among interiors of aquifers, aquifers and recharged water sources of rivers and ditches should be kept, and groundwater flow should be unobstructed. In addition, the necessary water storage space can be provided by fairly thick aquifers. In recharged areas of Yanzhou of Shandong, most of the area of superficial layer is composed of subsand which has good permeability, and aquifer is composed of medium and coarse sand. Fluctuation of water table in aquifer is 7-12m, and water level amplitude $H = 5\text{m}$. If calculation is done based on average yield of water $u = 0.138$, the amount of water that can be stored may reach 227 million cubic meters in the recharged area covering 334 square kilometers.

2.2 Water source conditions: Stable and reliable water source should be guaranteed for recharge projects. The amount of water replenished should satisfy designed requirement of the recharged area. Corresponding key interception and storage projects should be available to divert the amount of water needed for recharge in case surface runoff of the local river channels, flood water of high-water period, discharged water of reservoir during flood season, or "guest water" from outside are used as source of replenishment. In recharged area of Yanzhou of Shandong, river water of Sihe is mainly diverted for feeding. Annual average runoff volume at two water outlets is 280 million cubic meters where package of key projects is available, the amount of water that can be diverted during average year is 106 million cubic meters plus 29-million-cubic-meter of water from Guangfu River, the total amount of 135 million cubic meters of water can meet the designed amount for replenishment.

In addition, other factors such as the existing conditions of projects, how to use the available facilities of river channels, ditches, and ponds for recharge project construction and to improve infiltration effect and save investment should be taken into account. Most of the recharge projects in Shandong are operated in combination with the existing channels and ditches. In recharged area of Yanzhou, 11 river channels (120 km long) and 1740-kilometer-long drainage ditches are utilized in combination with newly constructed projects which gained satisfactory results.

3. Types

According to different natural and socio-economic conditions, several types of groundwater recharge projects are identified.

3.1 Spreading through ditch and channel: This is a lateral

groundwater recharge method by using water from rivers and ditches. It is favorable to divert water source with great flow discharge for extensive replenishment. But because of the great limitations to geological and hydrogeological conditions, lateral seepage is generally uneven. This type of recharge is mostly practised in Shandong. Specific methods include spreading through surface ditch and channel, and spreading recharge by combination of surface water with groundwater.

3.2 Field seepage recharge: This is a vertical recharge method through seepage over extensive area. Submerging of check basin, and flooding with water stored in winter can be adopted, and flooding with water diverted can be practised on sandbank wasteland formed on ancient channels.

3.3 Pit and pond recharge: Pits and ponds can be used to collect rainwater or divert introduced water for seepage recharge. Pits and ponds should be connected with aquifers or in some cases wells can be dug in pits or ponds to improve seepage effect.

3.4 Well injection recharge: It is mainly adopted when aquifers are fairly deep or in case other methods can not gain good results. Pressureless injection and pressure injection are available.

3.5 Recharge with escaped water from reservoir in flood season: Under the prerequisite of guaranteeing reservoir safety, escape time can be extended in a planned way to promote bank seepage via central riverbed at downstream. This is a non-engineering measure with low cost, but flood water should be regulated. During the flood season in 1990, the flood escape scheme of "small discharge but long duration" was adopted for Taihe reservoir. As a result, flood resources of 97 million cubic meters were effectively replenished to the water source at downstream for urban water supply. It is estimated that benefits of various types reach 2.52 million yuan.

4. Economic Benefits

The principal benefit of groundwater recharge is to gain a balance between excavation and replenishment and that between water source supply and water demand by means of artificial feed for the purpose of generating a series of economic benefits in production increase, expenditure reduction and disaster alleviation. Effect of groundwater recharge can be illustrated by using data from recharged area of Yanzhou. Water consumption and replenishment in recharged area during the period of 1984 to 1987 are listed in Table 1.

From the table one can see that precipitation and peripheral feed covering the four years only makes up 55.3% of the total replenished while 44.7% of the replenishment comes from artificial recharge. Without artificial recharge, the amount of water deficient in the four years would be 642.3mm, accounting for 43.9% of the amount excavated. In other word, the amount of

Table 1 Statistics of groundwater regulation in replenished area (unit:mm)

Year	Amount recharged (AR)				Amount consumed (AC)				
	PP	PR	AR	Total	IC	Excavation ID	Total	PE	Grand total
1984	351.8	39.8	143.1	534.7	218.2	25.2	243.7	39	287.7
1985	242.2	19.2	150.3	411.7	289.2	25.8	315.0	58	373.0
1986	136.6	27.9	236.4	400.9	421.3	25.9	447.2	29.4	476.6
1987	131.4	25.1	255.3	411.8	430.0	26.0	456.0	28	484.0
Grand total	862	112	785.1	1759.1	1358.7	103.2	1461.9	154.4	1616.3

Note: PP=Precipitation percolation; PR=Peripheral recharge; AR=Artific recharge; IC=Crop irrigation; ID=Industrty and domestic; PE=Phrea evaporation

excavation could only satisfy 56.1% of the requirement, and annual average water deficit would be 160.6mm, or per square kilometer water deficit was 160,600 cubic meters. The specific benefit gained from equilibrium of groundwater resources due to replenishment are described below.

4.1 Reduction of consumption and expenditure for water pumpage due to groundwater rise

The rise of groundwater table in recharged area led to the reduction of lift of pump, per cubic meter of water energy consumption and the cost. Bm formula for calculating annual economic benefit is given as:

$$B_m = 0.001 I \cdot P \cdot H \cdot W$$

where I = power consumed for lifting per thousand ton of water per meter (KWH/100m.T)
P = per unit price of electricity (yuan/KWH)
H = lifting amplitude (m)
W = annual water lifted (T)
Bm = annual economic benefit (yuan)

The economic benefit generated due to reduction of power consumption from 9820 motor-driven wells as a result of groundwater table rise during 1984 to 1987 is listed in Table 2.

4.2 Reduction of cost for motor-driven-well replacement and innovation due to groundwater rise

According to statistics, if groundwater table continued to drop without replenishment, the cost for reinstalling of 1800 wells used for lowering pump height (average 4m) would be 14.4 million yuan (800 yuan for a single well), and 15.4 million yuan would be needed to replace another 1100 wells (1400 yuan for installations and accessories) covering the four years from 1984

Table 2 Economic benefit from reduction of power consumption during 1984-1987

Year	Annual average GW depth(m)		H (m)	P (yuan)	W (10,000 cu.m)	Annual benefit (10,000 yuan)
	Recharged area	Natural fed area				
1984	5.57	7.50	1.93	0.019	6575	124.93
1985	3.36	7.15	3.79	0.038	856	32.53
1986	3.66	7.67	4.01	0.040	12241	489.64
1987	3.65	7.55	3.90	0.039	12381	482.56
Total					32053	1129.96
Mean					8031.3	282.49

Note: H = lifting amplitude; P = per unit price of electricity saved; W = annual water lifted

to 1987 in recharged areas of Yanzhou. The available recharge projects saved 29,8 million yuan for renovation of the existing installations, and an average of 745,000 yuan was saved each year.

4.3 Benefit for industry and agriculture due to groundwater replenishment

Agricultural production benefitted from replenishment includes expansion of irrigated area, or the increase of net output of crops caused by the increase of irrigation water amount and irrigation frequency, and shortening of irrigation cycle or rotational irrigation cycle. Statistics of recharged areas in Yanzhou indicated that annual average production increase after replenishment is 300kg/ha. If calculation is done based on average 0.6 yuan per kg of grain, contribution coefficient of irrigation efficiency of 0.3, then production increase efficiency of replenishment would be 54 yuan/ha/year. If industrial water supply related replenishment efficiency B_i is calculated on the basis of allocated portion from net industrial output value corresponding to water supply, the formula then would be given as

$$B_i = \frac{W}{W_0} \cdot I \cdot Y$$

where W = water supply for industry (m)
 W_0 = water consumed for 10,000 yuan of output value
 (m /10,000 yuan)
 I = rate of net output value of industry
 Y = allocated coefficient of water supply efficiency,
 normally being 0.05-0.10

5. Economic Evaluation

Economic evaluation refers to that on cost-benefit comparison in the operational period after the completion of the project, and

it is an important component of feasibility analysis of the project. In economic evaluation, economic efficiency index of the project is quantitatively calculated to judge its economic rationality. Recharge project is a public work which is evaluated by calculating cost-benefit ratio R , net present value NPV, and payback period P_t .

Calculation formula for indexes of R , NPV, and P_t is given as

$$R = \frac{\sum_{t=1}^n \frac{B_t - C_t}{(1+i)^t}}{K_0}$$

where B_t = efficiency value of year t (10,000 yuan)
 C_t = operation and management expenditure for year t (10,000 yuan)
 K_0 = investment of the project (present value)
 n = service life of the project (year)
 i = reference coefficient
 NPV =

symbols in the formula are the same as the previous one.
 Calculation formula for P_t is given as

t that satisfies the equality would be P_t , meanings of the symbols are the same as the previous one.

Recharge project has not only high efficiency but the economic efficiency index resulted from comparisons of efficiency value and expenditure is also superior to threshold value of economic rationality ($R > 1$, $NPV > 0$, $P_t < \text{prescribed payback period } [T]$ was regarded to be economically reasonable). Take recharge project in Yanzhou as an example. The project diverts Sihe and Guangfu rivers for replenishment. The designed recharge volume is 18.5m³/s, the designed annual total water recharged is 135 million cubic meters, total investment of the project is 10.22 million yuan, prescribed service life of the project $n = 20$ years, and reference coefficient $i = 15\%$. In the light of the above data, the economic evaluation of the project is discussed below.

5.2 Calculations of project benefit

$B_t = B_{t1} + B_{t2} + B_{t3}$
 where B_t = annual total benefit (10,000 yuan)
 B_{t1} = annual irrigation cost saved (10,000 yuan)
 B_{t2} = benefit from reduction of replacement and innovation expenditures of motor-driven pump (10,000 yuan)
 B_{t3} = benefit of agricultural production increased value (10,000 yuan)
 $B_t = 282.49 + 74.5 + 180.36 = 537.35$ (10,000 yuan)

5.2 Annual operation and management expenditure

It makes up about 5% of the total investment.

Ct = 511,000 yuan

5.3 Calculations of economic efficiency index

As Bt and Ct are means, they are also referred to as Bo and Co, then,

$$R = \frac{Bo[P.W.F]}{Co[P.W.F] + Ko}$$

where [P.W.F] is present value factor, by substituting n and i into the formula, calculations of [P.W.F] = 6.2592.

$$537.35 \times 6.2592$$

$$R = \frac{51.1 \times 6.2592 + 1022}{537.35 \times 6.2592 + 1022} = 2.50$$

$$\begin{aligned} NPV &= (Bo-Co) - lg(Bo-Co-Ko) \\ &= (537.35 - 51.1) \times 6.2592 - 1022 \\ &= 2021.58 \text{ (10,000 yuan)} \\ &= lg(Bo-Co) - lg(Bo-Co-Ko) \end{aligned}$$

$$\begin{aligned} Pt &= \frac{lg(1+i)}{lg486.25 - lg(332-95)} \\ &= \frac{lg1.15}{lg486.25 - lg(332-95)} \\ &= 2.72 \text{ (year)} \end{aligned}$$

Since the above indexes of R, NPV and Pt are far superior to the prescribed standard, the economic evaluation of the project is regarded to be rational. The economic evaluation indexes of other recharge projects are similar. Economic efficiency indexes of part of recharge projects in Shandong are calculated and results are listed in Table 3.

Table 3 Economic efficiency indexes of part of recharge projects in Shandong

Recharge project	Amount recharged (m.)	Ko*	Co*	Bo*	R	Pt (year)
Wanghe Laizhou	2800	1599	75	462	1.59	6.03
Huangshuihe, Longkou	3958	6320	348	2825	3.20	2.17
Huanghe diversion, Changyi (trunk)	2000	558	27.9	342.7	3.33	2.11

Note: 0.12 is taken as reference coefficient, service life is 20 years. * denotes the measurement being 10,000 yuan.

6. Eco-environmental Benefit

Eco-environmental benefit of the recharge projects refers mainly to the mitigation of a series of eco-environmental issues caused by overdraft. According to data from Shandong, in 1989 the amount

of groundwater excavated was 11.9 billion cubic meters, and overdraft, 4.4 billion cubic meters. With the exception of the five prefectures and cities along the Huanghe River, water for agricultural and industrial production of the other 11 prefectures and cities mainly depended upon groundwater and about 40% of the water were obtained from overdraft. Recent statistics of 11 prefectures and cities including Yantai and Weifang indicated that annual overdraft was 2.5 billion cubic meters. Ratio of actual groundwater excavated to exploitable amount is 1.28:1. Cone of depression covering an area of 16,000 sq. km was formed in the province due to overdraft. The lowest point in the depression is 23m, ground subsidence in the scope of the depression have affected house building and safe and normal utilization of other industrial installations. Marine transgression and salt-water intrusion occurred in coastal zones due to drop of freshwater table. Freshwater aquifer was judged following the standard of 250mg/L of oxygenated ion content contained in freshwater as marine transgression and salt water intrusion. Up to 1991, the intruded area totalled 593.7 sq.km. The most serious cases occurred in Laizhou and Longkou where the intruded area has been expanded to 323.9 sq. km since the very beginning in 1976. This has seriously affected industrial and agricultural production.

According to incomplete statistics that nearly 50,000 ha of cultivated land have been affected or lost irrigation capability. About 10,000 motor-driven-wells were abandoned and secondary salinization-alkalization occurred to some of the farmlands. Drinking water for man and animals became inadequate in some villages. Since the direct cause for marine transgression is overdraft, the only solution is groundwater replenishment. Replenishment project to intercept and store local flood water is underway in Laizhou, included are three barrages, 2000 percolation wells, and 500 percolation canals. They can play an effective role in preventing marine transgression and salt water intrusion, and providing drinking water for man and animals.

7. Discussion

7.1 Facts proved that groundwater recharge technique applied in places where conditions are permitted is a strategically effective way to mitigate water supply and demand contradictions in North China. As this kind of projects falls into the category of infrastructure, the tangible economic results and eco-environmental effect are of social in nature, indirectness and integrity, unified planning and organization should be conducted or the chance would be bungled.

7.2 The amount of water spread should be correctly designed according to geological, hydrogeological conditions, source conditions and groundwater excavation and replenishment regimes because this is a critical concern to the extent of economic benefit of recharge. In places where natural rivers and ditches are utilized for replenishment project, the amount of water regulated should be properly determined to

avoid other adverse effects induced.

- 7.3 Water quality used as source for replenishment is a worrying issue in introducing recharge projects. Hence, efforts should be made to protect upstream water source to guarantee the standard of water quality for recharge.

References

- [1] Yan Zhenyuan, Bai Yuhui (ed.), 1992. Principles and Method of Calculation in Economics of Irrigation. Qingdao: Qingdao Oceanography University Press.
- [2] Shandong Provincial Academy of Sciences, 1990. A Study on Current State of Marine Transgression and Salt Water Intrusion in East Shandong and Countermeasures.
- [3] Song Yongqiang, Tan Yange, 1988. A Summary on Groundwater Recharge Technique in Yanzhou. Water Conservancy Bureau of Yanzhou.

COMMUNITY PARTICIPATION IN WATER HARVESTING
EXPERIENCES AND LESSONS FROM HOMABAY
DISTRICT NYANZA PROVINCE KENYA

JOHNSON AKOKO OUKO
DISTRICT SOIL & WATER CONSERVATION OFFICER
MINISTRY OF AGRICULTURE, LIVESTOCK
DEVELOPMENT, AND MARKETING

INTRODUCTION

HomaBay district has a land size of 3121 km² out of which 2260 km² can be termed as agricultural arable land.

Administratively its subdivided into 10 divisions (see appendix 1), possessing 7 different AEZ (see appendix II) population is about 849,431 persons with a density of 214 persons/km².

The area of study is East Karachuonyo division Rambira location. The division lies in the lower region (Lake basin) of the district with an altitude of 1135-1500m above sea level.

AEZ is predominantly LM3 (iii) cotton zone (marginal) found in zone III/IV with rainfall of between 700-1200mm per year varying between the months. Rains fall intermittently and are uneven in nature (see appendix III. Gendia station)

Soil are predominantly sandy on the eastern parts while the western parts and next to the lake shore have heavy black cotton soils (vertisols).

Agriculturally the area is marginal with farmers practising subsistence farming. Major crops are sorghum, groundnuts, cassava, maize and cotton, while for livestock indigenous cattle (zebus) and shoats reared. Another major economic activity is fishing in Lake Victoria.

The need: for intervention.

Due to the unreliable nature of the rains and the high evapotranspiration rate, various problems could be foreseen by the farmers.

A PRA to get to know the real situation was instituted by the national soil and water conservation programme (SIDA funded) within the ministry of agriculture livestock development and marketing.

Initially a two week reconnaissance survey was done which identified possible sites of which three were identified.

- i.e
- (i) Seka/Okundi catchment - E/Karachuonyo
 - (ii) Lambwe catchment - Mbita division
 - (iii) School participation in water harvesting, Wahambla and Kotieno primary school.

Of all these Seka/Okundi catchment was selected as the basis of our PRA as the community showed a higher affinity for participation in developmental activities.

The participatory rural appraisal (PRA) of one week was organised by the district soil conservation officer and funded by SIDA.

Participants were drawn from various government departments and NGOs working within the division.

During the PRA a total of 80 farmers 30 women and 50 men contributed to the discussions as they were sensitised on community empowerment and responsibilities.

The PRA revealed the problems and possible opportunities for the community and possible ways of having a joint effort between the community and implementing agencies.

It was noted that women played a major role in most families, being involved in fetching water, firewood, all household chores small business and all agricultural activities, men were only involved actively during land preparation. Hence not very many man hours are put into economic use.

On 5th day of the PRA a community action plan was drawn and 80 farmers participated in the decision making and ranking of problems.

The problems were ranked and possible opportunities given as below:-

- (i) Water

Major problem within area as during the draught period of five months women and children

have to move upto 10 kms in search of water for both domestic and livestock consumption. Here opportunities were, digging of shallow wells, building of a sand dam along Rambira stream, building of ferrocement tank in school within locality or connect the main water supply line from the Awach River 15 kms away.

(ii) Crop production

brought about by acute soil erosion deafforestation low crop husbandry and erratic rains resulting in low crop yields hence an acute food shortage.

(iii) Health

Health centres are between 5-7kms away. To ensure more community empowerment and participation the farmers resolved to form a committee to eversee all future agriculture activities and follow-up on the PRA resolutions. The community resolved to immediately start work on a sand dam if a donor could assist. An arrangement was also agreed on to provide locally available materials e.g. hardcore, sand and water men were to collect hardcore and help skilled workers in dam works while women were to provide sand and water. SIDA through the national soil and water conservation programme is the donor. Successively a community conservation committee was elected comprising of 9 men and 3 women who were then given the authority to act on behalf of the communities and be the co-ordinators of all environmental conservation activities.

(iv) All farmers to adhere to soil and water conservation practices. Therefore the need for the study was justified on completion of the PRA as a need to provide water both in quantity and quality as an entry point to conservation activities within the area.

A conservation /dam committee was elected during the final day of the PRA and 9 men 3 women were elected.

Objective of the project.

- (i) Introduce traditional and drought tolerant crops using water harvesting techniques for crop production.
- (ii) Provide water for domestic and livestock consumption, as an entry point to water harvesting
- (iii) Reafforestation of catchment area.
- (iv) Reduced erosion through an elaborate conservation work

(v) Improved food security and income.

Site identification of the dam was enabled by the community who proposed Rambira stream a seasonal river instead of Arua stream because of the farmers accessibility and good rock base; running across the narrow section of the stream.

Area was characterised by huge sand deposits and PRA revealed. This place to be the focal area for watering during the dry season, a period when sand was scooped out to get water hence our intervention was only to improve on the indigenous practice.

To embark on the project community resolved to open up the site by rehabilitating a 500m rural access road with men clearing the undergrowth while women used hoes to pave the road initially problem arose from community members close to the dam that the government wanted to take over their land. A few meetings held by the community, conservation committee and implementors helped alleviate this fear. In conjunction with the forestry department 1000 seedlings were provided which were planted around the project site by the community under the supervision of the committee.

Dam construction

While the implementing agency concentrated on survey work, the community embarked on collection of hardcore / stones and sand. To facilitate this, they were organised into five working groups of which were to work on a weekly basis, each group was put under the supervision of two committee members.

Stone collection was given priority as sand and water could be found within the streambed. 2 women groups in the location were involved in collection of water, sand and clearing of the rock base at the dam site.

A further motivation was given to them through the distribution of relief food i.e maize, beans on site in conjunction with the office of the President.

Though the ministry provided for skilled artisans, the community went a step ahead and provided three local artisans to ease the work.

To construct the foundation a team of 10 men dug a hole 0.65m wide 12m in length and 0.5m deep to reach in the proper rock for standing of the sub-surface dam.

The dam is mostly constructed in stages in order to keep sufficiently high water velocity, so that fine particles are washed out while the coarse particles settle of which also depend on the sediment transport rate of respective river.

We've currently constructed up to the second level, giving stage of 0.75m for the foundation and 0.5m for the remaining level. Concrete mixture ratio used was at masonry in mortar 1:4 To combine all the stages smoothly one is required to remove top layer of cement mortar, clean concrete brush and water then make old concrete wet before new casting is done. This ensure no leakages are experienced, further strengthening is done on the extended walls by use of twisted bars and masonry - mortar mixture in wire, after each 10cm level.

Water points for livestock and the public are currently under construction with the pipe already placed to enable supply by gravity, there community have been involved in arranging and transportation of stones to the site of the cattle trough During the last dry spell of Nov-Dec '94 the already constructed stage helped the community both for livestock consumption and human hence lowering the distance the women take to get water i.e 7km to 1km hence providing more time for concentrating on conservation activities and farming.

It was evident that larger areas were put under crop as the farmers could go to the farms early instead of looking for water first.

Water harvesting for crop production

With the onset of the study community was introduced to improved contour ridges and contour bunds and given serena sorghum to plant. Results indicated an improved yield on the crop Of 2 bags - 5 bags /acre. This brought a further need by the farmers for the other methods of micro-catchment systems within farms as they realized this would be a way of alleviating the food shortage problem

The role of the ministry was specifically planning and layout of the structure while the construction aspect was left to the farmer, though the large volume of soils when constructing trapezoidal bunds proved a hindrance to its development.

Finally its realised that when time come for commissioning of the dam its maintenance and protection will be easier because of the high level of participation of the community, of

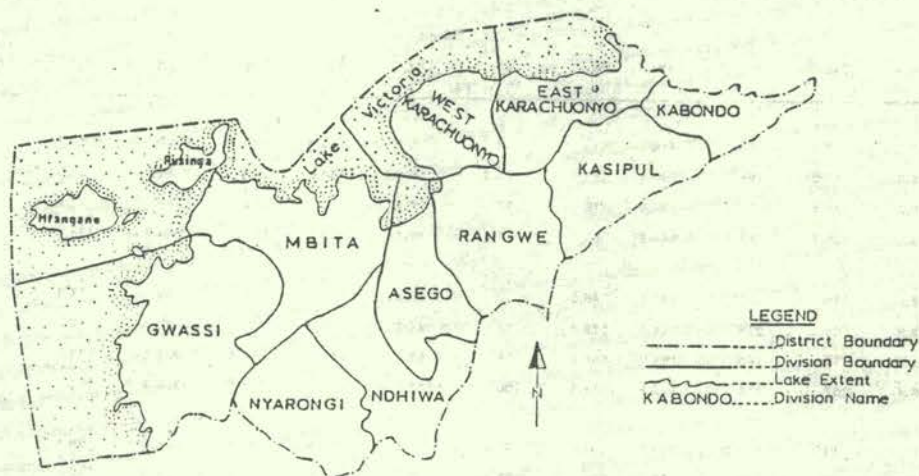
significance is the fact that though farmers are quite willing to provide labour in the initial phases more provision should be given by the donors to provide a certain percentage of the labour and not to leave everything to the farmers because as of now an acute labor shortage exists due to rural - urban migration.

References

1. MINISTRY OF WATER DEVELOPMENT (1992)
"Guidelines for the design construction and rehabilitation of small dams and Pans in Kenya".
2. Nissen - Petersson. E. and Dr. Michael Lee (1990)
Water Harvesting - Construction of sand dams and subsurface dams"
3. Will Critchley Klaus Surgert. C.Chapman. M.Kinkel 1991
"Water Harvesting" Food and Agriculture Organizations of the United Nations Rome
1991 AGL/MISS/17/91.
4. OUKO J.A 1992
"Participatory Rural Appraisal Report. Okundi catchment" Homabay District ministry
of Agriculture Livestock development and Marketing.

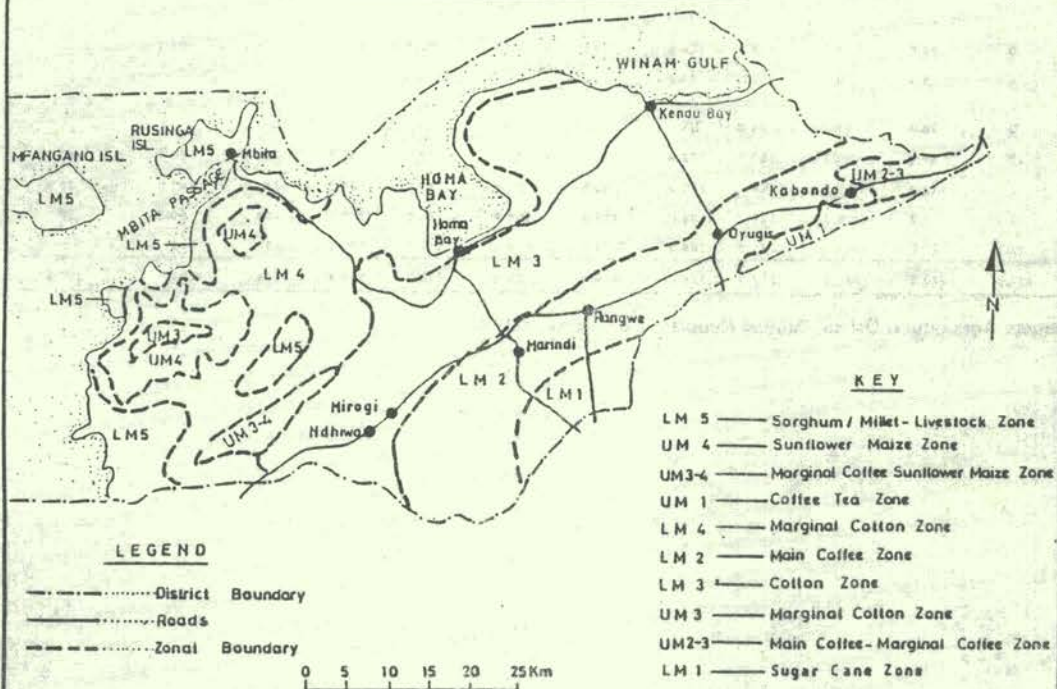
appendix 1

HOMA-BAY DISTRICT ADMINISTRATIVE UNITS



appendix II

HOMA - BAY DISTRICT AGRO-ECOLOGICAL ZONES



appendix III

Mean Monthly Rainfall, 1988-92

Year/ Station	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988												
H/Bay FTC	65.1	5.4	135.5	426	515	0	0	79.6	193	128	49.1	5.0
Gendia	69.8	25.0	156	290	257	58.2	0	106.0	140	92.7	92.0	0
Oyugie	135.0	75.5	75.6	225.8	178	297	98.1	0	212	184	92.2	0
Sub-total	269.9	105.9	367.1	941.8	950	355.2	98.1	185.6	545	384.7	233.3	5
1989												
H/Bay FTC	8.5	194	71	124.8	146.0	0	21.8	122.4	64	92	67.3	156.7
Gendia	28.9	106	228	116.0	222.9	22	44.8	28.0	113	41.7	48	187
Oyugie	13.0	57	140	185.0	664.6	78	55.7	164	82.6	236.6	185.7	46.3
Sub-total	50.4	267	439	425.8	1033.5	100	122.3	314.4	259.6	370.3	301	432
1990												
H/Bay FTC	0	30.9	180.0	220.5	217.5	198.3	31.3	214.8	21.3	74.0	NR	NR
Gendia	50.2	0	131.9	175.1	206.6	38.1	7.4	133.8	11.5	95.6	NR	NR
Oyugie	79.4	214.3	184.0	347.9	300.4	82.2	109.2	162	113.2	114.6	NR	NR
Sub-total	129.6	245.2	475.9	743.5	724.5	318.6	147.9	510.4	146	284.4	-	-
1991												
H/Bay FTC	0	41.1	48.0	94.1	182.1	104.3	0	0	34.0	0	NR	NR
Gendia	102.9	0	135.1	73.1	170.5	101.4	12.9	10	0	177.8	NR	NR
Oyugie	127.5	25.0	135.1	0	238.7	92.4	5.0	96.4	57.9	105.8	NR	NR
Mbita	92.0	26.0	79.4	46.2	156.4	0.0	24.1	22.2	11.0	NR	NR	NR
Sub-total	322.4	92.1	397.6	212.4	747.7	298.1	52	128.6	102.9	283.6	-	-
1992												
H/Bay FTC	0	33.5	97.5	146.6	153.8	114.8	70.6	38.1	182.5	46.1	104.1	-
Lwanda/ Mbita	1	25.3	0	116.0	71.6	-	-	-	-	-	-	-
Megunge	0	38.0	21	34.6	NR	-	-	-	-	-	-	-
Gendia	67	31.9	50.7	193.3	188.8	140.5	63.6	72.5	69.1	85.1	50	40
Asumbi	0	32.8	53.8	NR	310.7	250.5	71.4	83.2	146.2	132.0	192.6	32.5
Oyugie	22	2.2	108.2	124	165.0	117.3	104.4	116.6	110	100	90.3	30
Othoro	27.5	27.5	86.2	238.2	289.8	252.4	118.6	137.8	140.1	135	100	-
Sub-total	117.5	222.5	331.2	1,217.3	1,179.4	875.6	428.5	448.2	649.9	498.2	537	102.5

Source: District Agricultural Office, Annual Reports, Homa Bay, 1993.

RATIONAL EXPLOITATION AND UTILIZATION OF WATER RESOURCE IN HEILONGJIONG PROVINCE

Zhang Guilan Zhang Xuqiang

(Geography Department, Haerbing Normal University, P.O. 150080)

Along with the development of industry and agriculture and improvement of the living standards, the exploitation and utilization of water resources in Heilongjiang Province are increasing rapidly. Meanwhile, because the spatial distributions of water resources are very uneven, and water resources doesn't mesh well with the land resources, additionally, water conservancy engineering does not meet the actual requirement, the rate of exploitation of water resources only reach 14 percent and the contradiction between supply and demand of water resources also become increasingly serious. Therefore, rational exploitation and utilization of water resources have become more important in this region.

1. Characteristics of water resources in Heilongjiang province

1.1 Lower than that of the whole nation of water resources for per capita and per ha. of cultivated land.

The annual average rainfall in Heilongjiang is 531.5 mm which is equal to 2492 billion cubic meters of rainwater, the annual average depth of runoff is 139.8 mm and its total amount is 655.8 billion cubic meters. Including underground water resources, the total amount of water resources is 772.2 billion cubic meters. The amount of water resources for per capita is 2093 cubic meters and accounts for 77.5 percent of that of the whole nation which is 2700 cubic meters. The amount of water resources for each Mu(667m²) of farmland is 504 cubic meters and equals to 28 percent of national average which is 1800 cubic meters. They are both lower than national average level.

1.2 Uneven regional distributions of water resources.

Regional distribution of runoff in Heilongjiang Province is not even: It is abundant in the east part and poor in the west part, abundant in mountainous areas while poor in plain regions. In the east parts of Yichun, Tieli, Hailin, Wanda mountainous areas, higher values of annual amount of runoff appear in the four regions respectively and the annual runoff depth is between 200 to 500 mm. Three regions with lower values of annual amount of runoff exist in Wanda Mountain close valley, Wokenhe river and Sanjiang low plain. Their annual runoff depth are between 25 - 150 mm. The tendency of spatial distribution of

annual runoff amount is in a good agreement with that of annual rainfall.

The regional distribution of groundwater resources' replenishing in Heilongjiang Province is severe variable: the total replenishing amount of groundwater resources is approximate 273 billion cubic meters. It is abundant in plain areas and poor in mountainous regions.

1.3 The surface water resources is incompatible with the land resources.

The area of arable land in Songnen Plain which is the main place for grain production in Heilongjiang, accounts for 45.6 percent of the total farmland in the province, but its amount of water only account for 5.7 percent. Therefore, the drought is severe ; the arable lands in Daxinganling district only accounts for 13.1 percent of the total farmland in Heilongjiang Province, but its water accounts for 58.2 percent of the total amount in the province; similarly, the arable lands in the Basin of Hulanhe River accounts for 17 percent, while its water resources only accounts for 7 percent. As a result, a severe contradiction between water supply and demand in agriculture is produced. Especially along with ever-increasing demand of water resources, the crisis of water shortage become more and more serious.

1.4 Uneven distribution in time of rainfall.

The yearly distribution of rainfall is not even: in Heilongjiang Province, rainfall distribution is extremely uneven in time. The amount of rainwater in the period from June to September accounts for 60 - 80 percent of annual total amount, while the amount of rainfall in the period from October and February only accounts for 5 percent, and the amount in the rest months merely accounts for 15-35 percent. In general, the maximum of monthly rainfall in a year often occurs in July, which accounts for 25-35 percent of the annual total amount, and even can be more than 50 percent in sometime.

The year-to-year distribution of rainwater is also uneven : the yearly rainfall in Heilongjiang Province is obviously characterized by year-to-year rotating variation of abundant water and low water. The big cycle is about 60-90 years and the small cycle is about 20 years.

Storm and heavy storm are frequent and concentrated: Heilongjiang province belongs to the provinces which is with a poor rainfall. Compared with the southern provinces in China, the annual rainfall is less, but storm and heavy storm are abundant, and the extreme value of rainfall in short-lasting storm is

beyond the maximum of in China. Most of the storms, which account for about 66 percent, concentratedly occurs in July and August.

2. Present situation and existing problems of exploitation and utilization water resources.

2.1 The severe contradiction between water supply and demand.

Under the condition of normal assurance frequency of 75 %, all kinds of water conservancy projects together can provide water of 14.03 billion cubic meters, but the total water demand for different trades and professions is 14.709 cubic meters. Through calculation of the balance between water supply and demand, surplus and deficit, the average rate of exploitation of water resources merely reaches fourteen percent and the average degree of water shortage is nineteen percent. Among the five districts, Nenjiang area is with the highest rate of exploitation of water resources, which is 21.1 percent, and its highest degree of water shortage is 25 percent. Among the sub-regions of each districts, these subregions where the degree of water shortage is beyond 30 percent, include these areas: from Jiangtiao to Sancha in Nenjiang district where the degree is 39 percent, in the basin of Lalin River in Songhua River basin where the degree is 35 percent, from Sancha River to Haerbin region where the degree is 33 percent, In the basin of Mulin River in Wusuli River basin where the degree is 31 percent. The area of these regions, where the degree of water shortage reaches 40 percent account for 11 percent of the total area in Heilongjiang Province, the area of these regions, where the degree of water shortage is 10- 40 percent account for 42 percent, and the area of these regions, where the degree of water shortage is below 10 percent, account for 47 percent.

2.2 Suffering from Water Pollution in different degree

The Natural water quality is good in Heilongjiang province. It meets the requirement of industry, agriculture and people's living in the main. However, because of the impacts of industrial and agricultural production, as well as mankind activities, water resources suffers from pollution in different degree in Heilongjiang province. Important sections of some rivers, for example in Songhua River, Mudan River, Tangwang River, Mulong River etc, the degree of water pollution surpasses the standard of water quality for irrigation, drinking and fishery. The groundwater of some chemical plant quarters already can't be drunken for water pollution. It greatly affect the production and people's health. Therefore, some practical and feasible measures, such as strengthening protection and management of water resources, preventing water pollution and carrying out

a comprehensive control against water pollution actively, are indispensable and should be performed in a great press.

2.3 Low capacity of water-supplying projects, many dangerous reservoirs and unmatched irrigation facilities.

Due to the lack of water conservancy facilities, additionally, there are not key projects in the major rivers, the capacity of regulation storage is very poor, the existing water conservancy facilities can't satisfy the water demand of industry, agriculture production and people's life.

According to statistical figures, the dangerous reservoirs in Heilongjiang province approximately account for 51 percent of total reservoirs. There are two dangerous reservoirs among twelve large reservoirs. Among 45 middle reservoirs, 27 reservoirs need strengthening because they are not up to the strengthening standard.

The efficient area of reservoirs in their irrigation areas merely accounts for 33 percent of the designed area. Moreover, the actual irrigated area of farmland accounts for 62 percent of the efficient area, and water conservancy works are unmatched. So, its profit is the lowest in the four kinds of means for water diversion.

3. The way for rational exploitation and utilization of water resources in Heilongjiang province.

3.1 Water saving

Water saving must be carried out in all aspects in the whole society. It means that according to the different conditions of industry, agriculture and people's life in rural areas and cities, different measures of economy and technology should be performed separately.

3.1.1 Industrial water saving

Industries need a great deal of water, especially metallurgy industry, papermaking, chemical industry. To Producing one ton of steel and iron, 20 cubic meters of water is required, one ton of paper needs 200 cubic meters of water. If the circulative utilization rate of water can be heightened, the actual water consumption will be lessened. The recovery rate of industry water in Japan was 36 percent in 1965, the output value of per 100 million Yen actually consumed

70 cubic meter of water every day. The recovery rate of industry water was raised up to 65 percent in 1975 and the actual water consumption for per 100 million Yen was decreased down to 37 cubic meters, which was approximately as much as a half of the original amount. Therefore, raising the reusing rate of water resources is an important solution to the problem of water shortage. Furthermore, it is favorable to protecting environment from the pollution of industrial waste water.

3.1.2 Agricultural water saving

Agriculture is the department with the largest water consumption in the whole society. Most of the water consumption in agriculture is used for farmland irrigation. Agricultural water requirement is greatly influenced by the natural precipitation. When rainwater is abundant, the water requirement for farmland irrigation is lowered. On the contrary, if rainfall is short, the water requirement for farmland irrigation will be increased. In a year with low water, the water requirement for farmland irrigation is more than that in a normal year, which aggravates the contradiction between rural agricultural and city industrial water consumption. Therefore, the effective water saving in agriculture plays a very important role in the water saving of the whole province and greatly mitigates the contradiction between industrial and rural agricultural water consumption.

There are many ways for water saving in farmland irrigation. In general, They are: (1) regulating planting structure of crops and lessen the area of crops which consume more water for irrigation; (2) carrying out a good repair of irrigation channels and ditches in order to lessen the loss of seepage during the course of water conveyance; (3) popularizing sprinkling irrigation, drip irrigation technology to reduce evaporation and leakage; (4) strengthening administration, carry out planned water supply, and promote the efficiency of water resources use etc.

3.1.3 Living water saving in city and country

The water consumption for living in city consists of two parts: one is for dwelling; the other is for public and others. In future, along with improvement of living standard, water demand for people's living will increase greatly. Part of the increase in water consumption for people's living is satisfied by some of the saved water in industry and agriculture, the other depends on the water saving of city itself. So, some measures and techniques of water saving should be widely carried out in people's life in city to raise the benefits of water utilization.

The concrete measures include (1) quickening the development and the popularization of water saving hygienic facilities. Such as, water saving taps, water saving toilet tools, water saving guns, water saving pedal of hot-water in bathroom. (2) quickly taking measures to carry out circulation water use in those units which are equipped with conditioner and cooling water. (3) carry on middle waterways' design and experiment of dwelling and public building.

3.2 Tapping new water resources and carrying out inter-basin water transfer

Considering from the two aspects: tapping new water resources and water saving, on the one hand, water wasting phenomena exist widely in production and living; on the other hand, there is still some water resources which can be exploited, such as, building reservoirs, cisterns, flood sluices etc. in large regions, and in small regions, rationally developing motor- pumped wells according to the actual conditions of the local farmland.

Considering from the characteristics of precipitation in the areas: due to the characteristics of alternation of low and high water years, and the annual rainfall concentrates in some months, additionally, storms occur frequently, the projects for water storage should be built at the appropriate site according to the actual condition of the local topography, and rainwater in years with high water or rainy seasons or during storms should be harvested for the mitigation of water shortage in years with low water or in dry seasons.

Considering from the regional distribution of rainfall and the surplus or deficit situation of regional water supply and demand: the normal average of annual rainfall is more in the east and less in the west, from less than 400 mm to 650 mm or so; those regions with developed industry, agriculture and dense population are poor in water, while those regions with under-developed industry, agriculture and sparse population are abundant in water. Therefore, field survey and discussion on the inter-basin water transfer should be carried on quickly in order to obtain the biggest benefits from all parts of water conservancy projects.

Heilongjiang province is an important base of grain production in China. In recent years, along with exploitation of Sanjian Plain, the auction of waste lands and the increase in crop price, the enthusiasm of peasants is greatly aroused, and the grain production is raised in a large scale. As a result, agricultural water requirement is increased rapidly, and the crisis of water shortage takes place in some regions. Therefore, new water sources should be investigated and exploited in a short time in this regions.

3.3 Artificial Precipitation

The variation of natural precipitation can cause the change of water resources in a large scale. Artificial rainwater can increase the whole quantity of water resources. If precipitation can be increased by 20 mm in large scopes, the whole quantity of water resources can be raised by 10 percent or so. The effect is very considerable.

Heilongjiang province is an important base of commodity grain and soybean in China. There are 150 million Mu of farmlands in the province and the agricultural water consumption is very large. In each year, 10- 30 million Mu of farmland suffer from droughts in different degree. Artificial precipitation is an important ways to solve the disaster of drought in agriculture. During the period of crop growth, grasping advantageous opportunities to carry out artificial precipitation can improve the rainwater use efficiency of farmland and decrease the loss of rainwater. Generally, the rate of water loss of flood irrigation in dry farmland can reach 30-60 percent, of sprinkling irrigation is 15-20 percent, while under the condition of 20-40 mm precipitation, all of the rainwater can be use in dry farmland. Therefore, artificial precipitation is the most effective way to solve the problem of water shortage in agriculture if it can be combined with some agricultural techniques, such as deep plough and soil loosening.

Artificial precipitation has been performed by plane and high cannon in nine cities and fifty-nine counties in Heilongjiang Province. However, because lands were rent and auctioned, the national lands have belonged to land users or its owners. It has some influence on artificial precipitation in a certain degree, which mainly is the high cost of artificial precipitation. Therefore, a good coordination work is very necessary.

3.4 Building more water treatment plants and making a full use of waste water

Water resources for per capita in Heilongjiang is 2093 cubic meters. According to the figure, the quantity of water resources for per capita in this province is not low, which is mainly attributed to the large area of land with a sparse population. In fact, because the regional population distribution in Heilongjiang province is severe different, and the quantity of water resources for per capita is also very different. In these regions, such as Qiqihare city, Suihua region, Songhuajiang region (include Haerbin city), where Industry and agriculture is well-developed and the population is dense, water resources is very short, which merely accounts for 60 percent of the average in the whole province and 50 percent of the national average. So, more new water sources should be

tapped by great efforts in these regions where water supply is under a great pressure.

The treated waste water which is up to the use standard is precious resources. The discharge of waste water in Heilongjiang is very large, but disposal rate is extremely low. The large discharge of foul water which is not given any treatment not only forms a great threat on the environment of the lower reaches, but also bring about a great waste of water resources. In foreign countries, It is common that the treated waste water from city is used for agricultural irrigation and industrial production as well as the replenishing of groundwater. Therefore, in those regions where water resources is short, water treatment plant should be constructed in a short time in order to make a good use of the city waste water.

3.5 Conscientiously strengthening the work of reinforcing reservoir to remove the potential danger and forming complete sets of irrigation engineering

Without safety and security, water conservancy projects can not produce the full benefit. Some large and middle reservoirs, which are not up to standard of consolidation, should be put in order according to their conditions of danger, then rebuilt and strengthened in groups and by stages, according to financial resources, large and part of middle reservoirs should be removed danger and strengthened in a short time. The work of removing danger and strengthening of reservoirs should be well-arranged and well-prepared beforehand in the light of their quality and quantity. The building materials should be supplied in time. At the same time, irrigation projects in irrigated regions should be quickly formed in a complete set in order to obtain the benefit of irrigation facilities as early as possible. Excepting these reservoirs which undertake the tasks of water supply recently, all irrigation projects should be formed in a complete set so as to bring about the benefit soon.

In view of the characteristics of the engineering for reservoir's reinforcing and forming in a complete set, which include the remoteness of reservoir's site, the great requirement quantity of concrete and sand, the necessity of good preparation of building materials and transportation, the situations including the late transmitted orders to lower levels and the late transported building materials must be changed as soon as possible.

3.6 Making a good use of rainwater for afforestation, irrigation and street washing in cities and towns.

Heilongjiang locates at the north-east part of China. The characteristics of the climate in the province causes low survival rate of trees, and among which the spring drought also is an important reason for it. How this problem can be resolved ? According to the obvious characteristics of rainfall in the province, which belongs to the rain-snow type, snow can be collected from the street and then piled at the sides of the street in Winter. When spring comes, the melt snow can be used for irrigation. Additionally, in the course of road construction, not only the necessary road construction index should be considered, but also these three aspects should be taken into account: (1). Road surface must be slight higher than its two sides which are used for afforestation. (2). Road surface must be high in the middle part and low in its two side parts, and is has a fixed angle of inclination. (3). Rain collection pool should be built at certain stage of road. So, the collected rainwater can be utilized for afforestation. It also can be utilized for street washing, and after which it is collected by natural gravity because of the inclination angle of road surface.

At present, in the course of road construction in Heilongjiang province, It is common that road surface is lower than the soil surface of its two sides. This problem should be given much attention in the course of road construction in future in order to promote the rate of afforestation. Furthermore, because the streets are not muddy any more, cities and towns will become more clean and beautiful.

Reference literature

- (1) Heilongjiang statistical yearbook, 1991-1994
- (2) The research group on the construction and management of city fundamental abilities, City Fundamental Facilities, Beijingyanshan publishing house, 1986.

Section 3

**ECOLOGIC AND ENVIRONMENTAL
ASPECTS**

EFFECT OF RAINWATER REUSE ON ECOLOGICAL ENVIRONMENT IN SHIYANG RIVER CATCHMENT

Jiong-lin SHI
Member of IWRA
Dept. of Water Resources Engin.
Gansu Agricultural University
Anning, Lanzhou, Gansu 730070
P. R. China

ABSTRACT

The shortage of FreshWater Resources (FWR) is a world-wide problem, especially in Shiyang River Catchment (SRC), which is one of arid inland rivers. The Ecological Environment (EE) was fragile. Desertification was very seriously.

This paper was first put forward the technique of storage irrigation mulched straw on the soil surface by biological conservation of soil water. Use Storage Irrigation Mulched Straw Technique (SIMST) to keep soil water: the Net Storage Irrigation Quota (NSIQ) is only 900-1050 m³/ha, which is the half of the Conventional Storage Irrigation Regime (CSIR), and the gross amount of Water-Saving (WS) in SRC is 486 million m³. So its Ecological, Socio-Economic Benefits (ESEB) are significant. It was thought that the establishment of high efficient eco-agriculture and the use of SIMST is a breakthrough. This technique had universal and practical value in arid and semi-arid area.

KEYWORDS: Rainwater Reuse, Storage Irrigation Mulched Straw Technique, Freshwater Resources Management, Eco-agriculture, Shiyang River Catchment.

1. THE ECOLOGICAL FEATURES OF SRW

In Shiyang River Catchment (SRC), there are several forms of Water Resources (WR) including RainWater (RW), glacier, Surface Water (SW), GroundWater (GW), et al. RW is the main component of FreshWater Resources (FWR). It not only determines and restricts the moisture condition in this district, but also influences the glacial development, formation and distribution in high mountain region, and changes rules of runoff in rivers.

The shortage of FWR is more acute in SRC (located at 37°09'N-39°29'N and 101°10'E-104°15'E), which lies in Hexi corridor, Gansu, China. South of SRC is Qilian Mountain (QM), North is MO which is surrounded by Batanjilin and Turngkerli desert. Water System of Shiyang River (WSSR) consists of eight tributaries. This catchment belongs to arid-desert region, its ecosystem is fragile. QM is water-producing region. In LR the region above 4,259 m is glacier with total area of 64.02 km², and the glacier reserves is 2,143.4 million m³ (Yang, 1991). The amount of thawing water in SRC is 3.76% of the amount of runoff. With the climate warming, the

glacier had withdrawn 8.9 m annually (Shi, 1993). There were 226,700 ha forest in 50's in QM region with the pasture around them. This constituted a favorable environment for water conservation. The forest area in 1980's decreased by 16.5% compared to that in 1970's, and the lower limit of forest belt went up from 1,900 m to 2,300 m. The abundant resources of precipitation and glacier are the main existent form of SWR in QM. The amount of mean annual runoff, which exported out of by eight rivers in WSSR, is 1,511 million m³. The total SWR to enter MO at the downstream of catchment has decreased 2% annually since 1950's, i.e. A amount of 1,042 million m³ of SWR were decreased every decade. The known linear relationship between SWR (Y) and decade (X) is :

$$Y=10.6437-0.1049 X \quad (R=0.999) \quad (1)$$

Thus the oasis was forced to withdraw from the north and desert invades toward the south at the speed of 10 m annually (Shi, 1993).

2. EFFECTS OF FWR DEVELOPMENT AND USE ON EE.

Water is the dominant ecological factor in arid area. Where there is water, there is an oasis. In the past 30 years, the change of water environment and water circulation (WC) made the effect of water on environment become more prominent in arid region. The utilization factor of Surface Water (SW) and GW is 146.48%. With the reduction of SWR flowed into the MO, GW has been extracted in large scale from 70's by Minqin people to irrigation fields and to make up for the deficiency of SWR. The annual pumped amount was 722 million m³ (Chen, 1992), and the amount of over-extracted is 3630 million m³ which formed pumping depression cone of 986 km². A total drop is about 10-30 m to date (Shi, 1991). The data 1979-1990 which were got from observatory wells in MO indicated there was a linear relationship between the drop of GWT (Y) and Year (X) as follows:

$$Y=70.3120-0.7735X, \quad R=0.998 \quad (2)$$

GWT drops down 0.6-1.0 m annually. The pattern of vicious WC at MO is: Pumping--> descent of GWT--> mineralization of water quality --> degeneration of water environment. MO is a collecting region of water and salt. Mean annual precipitation is 110 mm, and evaporation is 2,640 mm. The pattern of GW pumping is: extraction --> irrigation--> infiltration--> re-extraction--> re-irrigation--> re-infiltration. The salt content doubles with each cycle. The average degree of GW mineralization reaches from 4 to 10 g/l, and increases annually at the speed of 0.3 to 1.0 g/l. Using highly mineralized GW (4-10 g/l) to irrigate cropland repeatedly increased salinization acreage from 10,500 ha in 50's to 33,700 ha in the middle of 80's. 14,000 ha cultivated land were abandoned for the water shortage. The water resources were contaminated by industrial waste water, which in turn affected the chemical composition of GW.

The ecosystem composed of water, species and environment is the basis for human being's life. The growth environment of psammophytes has undergone fundamental changes because of the

shortage of SWR, the degradation of GWT and deterioration of water quality. The root system of Oleaste distributes shallowly, usually at 2-3 m. The growth of oleaste degenerates and dies when GWT descends to 4-6 m (Liu, 1992; Chen, 1991). Natural shrubs grow normally when GWT is above 5 m, their growth will degenerate and minority of them will die when GWT is 5-7 m (Chen, 1991 and Shi, 1993). The Ecological Water Table (EWT), which is good for the growth of psammophytes, should be maintained at 3.5-4.0 m by controlling the EAGW strictly.

Dust storm is regarded as symptom of oasis desertification. On May 5, 1993, a dust storm befell suddenly on a clear sky in SRC. Visibility is zero. Trees were fallen down and houses were collapsed under the average wind velocity of 25 m/s. The maximum wind velocity reached 34 m/s. As a result, 83 persons were killed, 262 injured and 42 missing. It damaged 393,000 ha of crop farms. This dust storm occurred 66 years ago in 1928.

3. EFFECT OF MULCH WITH STRAW ON STORAGE IRRIGATION

The technique of the storage irrigation with straw to mulch on the soil surface is a measure of biological conservation of soil water in ungrowing season. In Hexi corridor, farmers are used to Irrigate Farmland (IF) in form of Storage Irrigation (SI) in fall and winter with a long history. Abundant water from river in fall is used to IF, the water stored in field will satisfy the Water Need (WN) of germination and complementary period, and compensate the shortage of WN in spring dry season. This had been correct before the water storage works was built. The reservoirs had been built in succession on each river in SRC since 1949, and the exceptionally great NSIQ (1650 to 4500 m³/ha) was used, according to CSIR, namely storage irrigation with bare soil surface, to undertake SI, the water stored in the reservoirs was all used in SI in fall and winter, which made the ineffective evaporation periods last 6-7 months, and lot of moisture wasted.

Recently, this Mistaken Habit (MH) of irrigation had been controlled once and for all thought the NSIQ was reduced to some extent. These are the problems on the acknowledgement and policy from local government and WR management department, include the MH of farmers. So, MH must be controlled if FWR want to be Utilized Economically and Rationally (UER).

Mulch as defined here is any material on the Soil Surface (SS) in which continuous liquid water films from the soil through the mulch are not present. Therefore, a mulch could be plant residues, straw, gravel, sand, perlite, dry soil itself, plastics film or any number of other materials.

The rate of loss of water or flux of water vapor through mulches is generally very slow in comparison to the rate of loss of water from a moist SS. The reasons for this are that: (1) in order for water to be lost by evaporation from a mulched soil, the water must change from a liquid to a vapor at the SS. The water vapor must then diffuse through the thickness of mulch which significantly reduces the rate of loss when compared to a bare SS; (2) the mulch reduces the quantity of direct solar radiation reaching SS; and (3) mulches act as insulators to downward

conduction of head into the soil (Phillips, 1994).

SI can use water from flood period, which can make the reservoirs safety during flood period and raise UCWR. But, it will make the reservoirs empty in winter (this period stored water account for 12.4% of the total input of all year), and water used to irrigate seedlings become in rather short supply in spring of next year. The irrigation area is 0.286 million ha in all catchment and WN 1,014 million m^3 (include GW resources) if NSIQ is 1950 m^3/ha average and Utilization Factor of Canal System (UFCS) is 55%. Every year about one third of SWR are used in SI in ID, it was surprised that the NSIQ per ha was so big and the wasted FWR so much. According to the result of many-year-study, if FWR want to be UER and efficiently the aim can not be only focused on how to utilize FWR rationally during the growing season, the study of the rationality (include Irrigation Period (IP) and NSIQ) of farmer SI procedure is more important, namely whether one third of FWR was used efficiently or not. It was thought that the establishment of high efficient eco-agriculture and the use of SIMST is a breakthrough.

The method which had low cost and notable WS efficiency is the utilization of biological measure of WS. 3-5 days after irrigation, the straw are used to mulch SS about the depth of 3-5 cm, and check (ck) with CSIR of bare SS. The flux of water vapor through a mulch 0.1 cm thick, a dry layer of soil at SS, is taken to be 100%; this approximates a bare, smooth, moist soil. A mulch 2 cm thick is about as effective in preventing soil water evaporation as a mulch 5 cm thick (Phillips, 1984). The rate of loss of water reduces about 91% when the thickness of gravel increases from 1 cm to 9 cm (Sui, 1990). This technique has been tested at three experimental stations in Hexi Corridor (result see table 1 and 2). In table 1, the Soil Moisture Content (SMC) from 1992 to 1993 is 12.3% to 14.9% Pre-Irrigation (PI), and after 191 to 215 days SMC is 19.8% to 22.3% Before Spring Sowing (BSS), which account for above 85% of the Field Moisture Capacity (FMC) in Yimin. The difference of SMC were 2.5% to 0.7% in mulch treatment (19.3% to 21.6%) than in ck (22.3%). The mulch treatment of the same period (Sept. 25) of different NSIQ (1065 and 1350 m^3/ha), SMC of BSS have difference about 1.5% and WS about 285 m^3/ha in Yimin, difference between SMC of BSS and PI were 7.5% to 7.6%. It was illustrated that SMC of BSS will be high if NSIQ was also high.

SMC from 1992 to 1993 is 12.4% to 18.8% PI, and after 137 to 162 days SMC is 19.6% to 21.3% BSS in mulch treatment and 16.7% to 21.3% BSS in ck in Xiying. The difference of SMC increased 4.6% to 0.5% in ck1 (16.7%) than in mulch treatment (19.6% to 21.3%). The SMC (25.5%) of treatment 1 was out of the ordinary, the soil in field was muddy. The treatment of different NSIQ (treatment 2 and ck1) of the same period, the SMC of BSS was same and but WS about 600 m^3/ha , the difference between SMC of BSS and PI were 7.7% to 8.9% in Xiying. It was illustrated that WS efficiency was significant.

In Table 2, the SMC was 13.7% to 14.6% PI from 1993 to 1994, and after 164 to 197 days, SMC of BSS is 15.6% to 17.6% which account for above 67.2% of FMC (it was in middle level compared with the SMC of BSS in large area of bare field), the treatment and

Table 1 The experiments of storage irrigation in Hexi corridor in 1992 to 1993.

ID	Treatment	SI		SMC (%)			MPSM		ID
		IP	NSIQ	PI	BSS	DSBP	PI	BSS	
Yimin	1	25/9	1065	12.3	19.8	7.5	25/9	17/4	205
	2	25/9	1350	13.7	21.3	7.6	25/9	17/4	205
	3	10/9	1326	14.5	20.7	6.2	9/10	17/4	191
	4	9/10	1434	14.9	21.6	6.7	9/10	17/4	191
	ck	9/10	1857	14.6	22.3	7.7	9/10	17/4	191
Xiyiing	1	6/10	1050	18.8	25.5	6.7	6/10	15/3	162
	2	6/10	1350	13.6	21.3	7.7	6/10	15/3	162
	3	30/10	1350	14.6	19.6	5.0	30/10	13/3	137
	4	30/10	900	16.4	20.0	3.6	30/10	13/3	137
	ck1	6/10	1350	13.6	16.7	3.1	6/10	15/3	162
	ck2	6/10	1950	12.4	21.3	8.9	6/10	15/3	162

Note: MPSM = Measuring Period of Soil Moisture (date/month); IP = Irrigation Period (date/month); NSIQ = Net Storage Irrigation Quota (m³/ha); DSBP = Difference of SMC of BSS and PI; ID = Interval of days (days); ck = check experiment.

Table 2 The experiments of storage irrigation in Hexi corridor in 1993 to 1994.

ID	Treatment	I		SMC (%)			MPSM		ID
		IP	NSIQ	PI	BSS	DSBP	PI	BSS	
Yimin	1	20/9	1200	14.6	15.6	1.0	20/9	5/4	197
	2	20/9	1350	14.6	16.2	1.6	20/9	5/4	197
	3	20/9	1500	14.5	16.6	2.1	20/9	5/4	197
	4	20/9	1200	14.5	15.6	1.1	20/9	5/4	197
	5	20/9	1350	14.6	16.1	1.5	20/9	5/4	197
	6	24/10	1500	14.7	16.6	1.9	24/10	5/4	164
	7	24/10	1200	13.7	16.5	2.8	24/10	5/4	164
	8	24/10	1350	13.7	16.7	3.0	24/10	5/4	164
	9	24/10	1500	13.8	17.0	3.2	24/10	5/4	164
	ck1	24/10	1200	13.8	16.8	3.0	24/10	5/4	164
	ck2	24/10	1800	13.8	17.2	3.4	24/10	5/4	164
	ck3	24/10	2100	13.8	17.6	3.8	24/10	5/4	164

ck have little difference. At the same period, the difference of SMC, BSS and PI will raise along with the increase of NSIQ, that is very regular. SMC increases 0.7% in ck (average of 1800 m³/ha) than in mulch treatment (average of 1350 m³/ha) when NSIQ increases 450 m³/ha. The SMC of BSS in 1993 were less than in 1994 (in Table 1 and 2), the reason was less of the precipitation in winter in 1993 than in winter in 1992. It was showed that the soil water evaporation is significantly reduced for storage irrigation mulched

straw. By correlation of analysis, the effect of difference NSIQ on SMC of BSS had no significant difference. It is illustrated that SIMST had very significant of the biological conservation of soil water.

Agricultural production was based on the EE condition in field, if the latter was improved, it was enable the inside of eco-agriculture system to keep high efficient conversion mechanisms for fine role in cycle of materials, to enhance field output efficiency and UCWR. SIMST showed improving efficiency of EE in field. It showed obvious effect against wind erosion and water erosion, for WS and increasing in yield. This is the reason why mulching field with straw can WS of irrigation.

Analyses of WS efficiency: According to the experiments conducted from 1992 to 1994, it will WS of 900 m³/ha than conventional average NSIQ of 1950 m³/ha if SIMST is used, during early September to November, NSIQ was 1050 m³/ha. if UFCS was 55%, the gross amount of WS is 1636 m³/ha. When this technique was carried out on 286,000 ha area in SRC, 468 million m³ amount of water was saved, less than 400 million m³ of GW was pumped annually, so GW can be in balance condition, GWT go up year by year, and EWT of GW 3.5 to 4.0 m under ground can be maintain, ESEB is significant.

4. CONCLUSION

The storage irrigation mulched straw was a technique of the biological conservation of soil water. Straw mulching on the soil surface was a main measure of all improving microclimate in fields.

This technique have protection the structure of soil, resistance wind erosion and water erosion, and protection the environment against white pollution.

The periods of storage irrigation are September to October.

WS 468 million m³ and decreasing pumping GW 400 million m³ annually in SRC by conducting SIMST with biological preserving water measure. So that GW can be in balance condition, and its ESEB is most significant. The technique had universal and practical value in arid and semi-arid area.

REFERENCES

- Chen, Hesheng 1991. The Influence of Water Resources System Exploitation on Vegetation in Arid Northwest Area. Arid Resources and Environment. 5(1): pp. 57-65.
- Phillips, R. E. and Phillips, S. H. 1984. No-Tillage Agriculture-Principles and Practices. Van Nostrand Reinhold Company, USA.
- Shi, Jionglin 1991. The strategy for the development of Minqin oasis. Arid Resources and Environment. 5(4): pp.70-75.
- Shi, Jionglin and Liang, Sheng 1993. Oasis Desertification and Water Resources Utilization in Shiyang River Basin. Proceedings of the International Conference on Environmentally Sound Water Resources Utilization, in Bangkok, Vol. II, pp. III-240-245.

Sui, hongjian and Zeng, dechao 1990. The present of study and direction of development for mulched on soil surface. Transactions of CSAE. 6(4): PP.26-33.

Yang, zhenniang 1991. Glacier Water Resources in China. Gansu Science Press, China.

Yuan, Shenglu 1987. The Preliminary Studies for Ecological pumping Capacity of Groundwater in Minqin Oasis. Journal of Water and Soil Conservation. 1(2).

Yuan, Shenglu 1991. The Influence of Water Resources Exploitation on the Ecological Environment in Shiyang River basin. Arid Resources and environment, Vol. 5, No. 3, pp. 44-52.

TECHNOLOGICAL DEVELOPMENT, RAINWATER UTILIZATION, ECOLOGICAL CHANGES
AND ENVIRONMENTAL DEGRADATION IN THE
DRYLANDS OF EAST AFRICA

J. P. MSANGI
EGERTON UNIVERSITY

INTRODUCTION

The drylands of the world are commonly referred to as arid and/or semi-arid lands. All these lands are characterised by moisture deficiency. Technological development in most drylands the world over has been in the form of water supplement to enhance crop production or to ensure sustainable water supplies for both man and his animals. Efforts to ensure continued land productivity for crop and/or animal production have seen the introduction of heavy farm machinery, introduction and/or expansion of irrigated agriculture, heavy fertilizer and pesticides usage as well as the encouragement of permanent settlements where they never existed. In some of the areas, dams have been built to store water of the seasonal rivers to meet the demands during the dry seasons. In some others, dryland farming techniques in the form of micro-catchments, earth bunds and other western designed water harvesting techniques have been employed.

Climatically, these drylands experience low total annual rainfall, unevenly distributed and occurring in sporadic short intense storms. The temperatures are high throughout the year and high wind speeds are experienced for a good part of the year. Both high temperatures and high wind speeds cause high water losses through evaporation and evapo-transpiration. Often, the water losses far exceed the annual rainfall so that moisture deficits are more normal than exceptions.

Broadly speaking, there are no marked ecological variations in the drylands of the world. Animal and plant species do not vary greatly although water and vegetation cover are not uniformly distributed in these environments. The soils too are not uniform, they are of great variety with varying productivity. As such, some parts can support more plant growth than others due to the fact that the soils possess better water

holding capacities and therefore better nutrient retention levels. Where such soils exist, vegetation is more abundant and lasts longer than in the areas where soils are poor with high porosities or low permeabilities.

In Africa and indeed in East Africa, the drylands were for many years occupied by nomadic pastoralists, gatherers and shifting cultivators. The cultivators who farmed on the fringes and peripheries of the drylands and around the wetlands retreated to better watered areas during the dry seasons. In turn, the nomadic pastoralists roamed the dry plainlands during the wet seasons and retreated to the periphery areas where water and pasture was available during the dry seasons. This way, the lowlands were not over taxed as they had time to recover.

Drastic changes have taken place in the East African drylands since the introduction of western approaches to development. Western style development demands that lands be intensively used throughout the year. Western styled development has encouraged rapid population growth through medical and nutrition improvements. Rapid population growth on the other hand has demanded increased production of food and other consumer goods which in turn has demanded intensive utilization of all productive resources. This development approach has created institutions whose management require local community support, usually in monetary form. The dryland communities have been forced therefore to increase production to meet their needs as well as those of the created institutions. Institutions like central and local governments, schools, hospitals and the like require support in the form of taxes, school fees and other related levies.

The need to increase production of food and cash crops as well as animal products for use locally and for sale has necessitated the introduction of new technologies to the drylands; technologies whose success often depend on sedentary communities. Consequently, efforts have been made to have the shifting cultivators and nomadic pastoralists live in permanent settlements so that they can participate in the development of the introduced institutions and new operative systems. Permanent settlements often supplied with water from boreholes, wells and such other point sources are linked with cultivation supplemented with cattle keeping. Such practises usually exert great pressures on the land immediately surrounding the settlements. Pressures emanating from permanent cattle tracks and continuous land tillage without meaningful fallow periods quickly

exhaust the soil nutrients and result into low land productivity and low animal carrying capacities.

Land clearing to establish large scale farming deprives an area of its vegetative cover and render it bare during part of the year after harvest and/or before planting; a period which in the drylands may equal as much as six or more months in a year. Such land is therefore prone to be affected by various agents of erosion and become degraded after a few years. It is widely documented that land degradation ultimately leads to desertification. Desertification having been severally defined as the impoverishment of terrestrial ecosystems under the impact of man. Dregne in 1983 defined desertification as the process of deterioration in the dryland ecosystems that can be measured by reduced productivity of desirable plants, undesirable alterations in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration and increased hazards for human occupancy. Further, Ahmad and Kassas in 1987, categorically state that it is man's activities especially the over-use and misuse of dryland resources that cause land degradation leading to desertification.

Equally well documented are the adverse environmental impacts of man-made lakes. Changed ecological conditions which culminate into health problems, water logging and changed river productivity downstream the dam behind which these lakes form, almost always negate the good intentions of creating such dams. Man-made lakes and other improved water sources lead to sedentary pastoralism and sedentary agriculture. Sedentary pastoralism means extensive grazing of the land within reach of the settlements. It also means land clearing due to procurement of fuelwood and building timber and poles. Administrative centres and other institutions' needs encourage charcoal burning in the drylands which itself is an alternative means of securing the much needed cash by the dryland dwellers. Such cash assists them in meeting the imposed institutional demands. Hence many hectares of woodland and forest land have been and continue to be destroyed this way.

Sedentary agriculture on the other hand mean bush and woodland clearing to create farmland. Cleared vegetation is usually burnt to provide clean fields before planting. Where there is a shortage of farm labour, bushland is cleared using fire. After harvesting fields

are often set on fire to get rid of weeds and harvest residues. Grazing land is often set on fire at the end of the dry season to stimulate growth of fresh grass. Although a convenient way of clearing large land tracts, it is a very detrimental method as the fire often kills young trees and other living organisms which are necessary in an ecosystem. As such, fires, though a quick way of returning nutrients into the soil (potash) they alter the ecosystems sometimes killing the soil's ability to support trees and other plants.

DEVELOPMENT IN THE EAST AFRICAN DRYLANDS

It is widely documented that in East Africa, the drylands comprise over two thirds of the total land area and carry over quarter of the total population. These lands also carry over fifty percent of the livestock population. This is more so for Kenya and Tanzania mainland than for Uganda or the Zanzibar and Pemba islands. The drylands in Kenya and Tanzania are the home of most of the wildlife conserved in national parks and game reserves. These lands receive between 250 and 1000mm of rainfall annually and experience high evaporation rates of between 1500 and 2500mm per year.

Among the underlying causes of ecological changes and environmental degradation in the drylands of East Africa is inappropriate technological development strategies which ignore past traditional strategies. Under-scoring this fact, Lusigi in 1981 stated that.

"the pastoralist was responsive to his own needs, the requirements of his livestock and the local conditions. Severe and widespread environmental destruction was apparently avoided. When this flexibility was lost through new development such as national parks and permanent water supplies the traditional mechanisms for coping with ecological and economic crises began to break down. These developments among others, led to the present deterioration and to the current famine".

The above statement is very true of most of the drylands in East Africa and reflects the inability of the communities to support themselves during recurring droughts which often may culminate into famines.

Water, the most valuable and the most scarce resource in the drylands of East Africa has commonly been tapped through the building of water pans, dams and chacos and in some cases through the drilling of shallow wells and bore holes. Water is also available in a few natural lakes and small wetlands, seasonal rivers and a few perennial streams which traverse these lands but have their sources in better watered environments. Where available, the water source points have become the focal points of environmental degradation and induced ecological changes.

Often, it is the water points which are the starting points of environmental degradation. It has been stated that an average bore-hole/shallow well may yield 2000 litres per hour of water which could supply as many as 2,000 heads of cattle or 8,000 sheep/goats. (Otieno 1993). Such large concentration of animals around boreholes, wells and pans often devastate the surrounding environment. In many instances, natural vegetation (grass, brush and trees) gets completely overgrazed for large radii around such points to be replaced by forbs and poisonous species. Trails created by herds converging on the water points are vulnerable to severe soil erosion. At the same time, the heavily grazed land by such herds experiences soil compaction to the extent that water infiltration and therefore groundwater recharge gets reduced or prevented altogether as surface runoff quickly gets into rills and gullies to be conveyed away from such areas.

Field studies carried out in parts of the Pangani Valley, Dodoma, Singida, Shinyanga and Mbeya districts of Tanzania as well as those carried out in Marsabit, Kitui, Machakos, Turkana and Baringo districts in Kenya have demonstrated that the drylands have been heavily grazed and eroded around swamps, lakes and other water points. At such points, only small patches of tough grass and tufts characterise the shores of lakes and edges of many wetlands. For example, it was established that Lobo springs a 200 hectares (494 acres) wetland accommodated over 25,000 heads of cattle, sheep, goats and camels in 1982 and over 34,000 in 1990. Here, the 1990 field research established that the expected carrying capacity of this wetland was far exceeded by as many as 49,506 goats as compared to an excess of 37,000 in 1982 (that is if all the animals are converted into livestock units where one livestock unit equal to one cattle or

three goats/sheep per three acres of pasture in the dryland ecosystem. By 1990, the animal population at Loboï springs required 12,300 acres of land contrary to the available 494 acres. The animals counted in 1990 were thin with an unhealthy appearance.

From the foregoing, it becomes obvious that the Loboï springs were overstocked and overgrazing which has led to the heavily gullied and eroded landscape characterising the area. Goats and sheep as well as a few donkeys were observed uprooting tubers and any other edible greenery in sight.

Similarly, the area around lake Baringo was just as heavily overgrazed as that at Loboï springs. Around the lake shores, animal populations have increased steadily since the 1970s and 1980s to reach 97,000 animals in 1990 in an area of 352 hectares (869 acres). The density then was 275 animals per hectare, the carrying capacity of the area being only 869 livestock units; an excess of 96,131 units (which was 46,710 in 1986). Like in the case of Loboï springs, the shores of lake Baringo were heavily overgrazed so that there was no branch below two metres and no edible grass within two metres from the water edge. Only a broken thin belt of swampy vegetation and reeds fringed the lake.

Reasons given for keeping such high numbers of animals ranged from necessity to meet local demands and institutional requirements to economic hardships and necessary to overcome drought losses. Others included a sign of wealth and authority as well as to achieve local recognition. During 1982 and 1985 field surveys, the same scenario was found to be true around the western shores of Nyumba ya Mungu dam in Pangani Valley, the entire shore area of Mtera dam in Iringa District as well as the edges of Bahi swamps, shores of Matumbulu, Ikowa and Hombolo lakes in Dodoma and Kondoia districts in Tanzania. Branch coppicing and pods harvesting were widely practised in the districts visited in 1982, 1985 and 1990. This practice threatens tree regeneration, especially that of acacia, species which have proven the only type which can stand the harsh environmental conditions. In Baringo District, the dry plainlands, were dotted by goats and camels roaming the horizon stripping the land of grass, young trees and low tree branches (if any). The sheep and cattle on the other hand were concentrated around the wetlands where it is relatively cool and some grass grows.

Overgrazing has accelerated land degradation process in the drylands of East Africa because the overgrazed areas such as those in Baringo, Marsabit, Turkana, Monduli, Shinyanga, Dodoma and Singida Districts are completely depleted of vegetation during the dry seasons. Strong whirl winds pick and carry large quantities of soil from one area to another and a great deal of it often is seen high up in the atmosphere above the ground. This process contributes towards the aridity of the places as a lot of suspended dust in the atmosphere modify the temperature gradient, causing stabilization of the atmosphere and suppressing convection thereby inhibiting rainfall. (Macleod, 1984 on dust theory).

Firewood is the main source of fuel energy in the drylands. Charcoal is burnt mainly for sale to urban dwellers and administrative officials. These also use firewood purchased from vendors. In the study areas, many vehicles were sighted ferrying both charcoal and firewood to urban and market centres. Heaps of firewood and sacks of charcoal were seen placed by the road side awaiting to be sold or to be picked up by vehicles. While in Baringo and Turkana Districts trees and branches are cut mainly to construct shelters, in Singida, Dodoma and Iringa Districts, they are cut mainly for firewood, timber and brick burning besides charcoal burning. In the neighbourhoods of national parks, more firewood is used for lighting fires near cattle enclosures at night to scare wild animals.

In most of these drylands, it is the large Acacia commiphora trees which are preferred for charcoal. One big tree can produce three to four bags of charcoal if properly burned. Bearing the many bags used all over the drylands and their neighbouring towns and market centres, in homes, institutions and small firms, it becomes obvious that a great number of trees are felled everyday to meet this purpose alone. No wonder then, the drylands, where indigenous trees take up to 60 or 80 years to mature, are virtually bare of tree vegetation. No wonder then, the soils are scorched by the sun, loosened by the animal hooves, blown by the strong winds and washed away by the runoff resulting from the sporadic heavy rain storms. The drylands have virtually been stripped of the top soil. The majority of the areas have sandy soils interspersed with gravel and small stones deposited by disparting overland and sheet runoff.

Where cultivation is practised, tree branches and young trees are cut and used to fence off farms to prevent animal menaces. Because most

of the dryland communities diets are dominated by meat and milk, cultivation is practised alongside pastoralism. Around some homesteads, eucalyptus and prosopis trees have been planted to provide firewood, supplemental feed (prosopis pods) for goats and they do provide some protection to the soil against wind and water erosion. Tree planting is limited to few areas in Baringo, Turkana, Singida, Shinyanga and Dodoma Districts and elsewhere where donor or government sponsored projects exist. Widespread tree planting and tree conservation in the drylands is constrained by the fact that to many communities in the drylands, trees like grass are for animals. As such they are not to be conserved, rather they are to be utilized.

Studies carried out elsewhere have demonstrated that when one degrades a natural ecosystem, by overgrazing or deforestation, one simultaneously alters the surface albedo. When this happens, there is increased loss of heat from the surface which in turn creates a cold spot in the atmosphere and an increase in the rate of subsidence. The descending air is then warmed through the process of adiabatic compression which suppresses any vertical wind motion which could lead to cloud formation and rainfall. This causes an area to become rainless or have erratic and scanty rainfall. (Albedo theory by Charney 1975). This could partly explain the scanty erratic rainfall of the drylands in East Africa.

Both dryland farming and irrigated agriculture is practised throughout the drylands of East Africa. Dryland farming is scattered all over the areas in small farms ranging between $\frac{1}{2}$ - 2 acres. Irrigation farming on the other hand is practised in isolated pockets around the wetlands. There are also a few large irrigation schemes like Mbarali irrigation scheme in Iringa, Tanzania, Pekerra irrigation scheme in Baringo, Kenya and many others.

Some of the farmers practising dryland farming practise bush-fallow, slash and burn method of cultivation confirmed that after clearing acacia trees and other bushes and shrubs are either used to fence off the farm or burnt to clear land for digging. They also believe that burnt up farms are more fertile than unburnt ones. The lands under irrigation is also cleared and ploughed around the same time as those under dryland farming. This is done during February and planting takes place in either April or May in the case of north and central Tanzania as well as Baringo farms while in Iringa and other parts in the southwest part of Tanzania preparation

takes part much earlier. However, in all cases the land is dug up or ploughed during the dry season and left bare for sometime before planting takes place. Leaving ploughed fields bare accelerates the rate of wind erosion as this is also the period when temperatures and wind speeds are highest. Fields, whether tractor or oxen ploughed experience the greatest soil losses and the most rapid nutrient depletion.

The abandonment of exhausted farms has created open structured ecosystems throughout the drylands which further encourage accelerated wind and water erosion. Continued irrigation in some of the areas which are often not adequately drained has led to water logging and salinization. Pekerra Irrigation Scheme for example, started way back in 1957, has experienced loss of many hectares of land due to salinization. Also some fish ponds on the scheme were ruined and abandoned due to high accumulations of salts in the water draining from nearby farms. Furthermore saline and alkaline soils are very common in drylands where they have formed naturally under the prevailing climatic conditions. Whether naturally formed or whether through irrigation practices, saline and sodic soils are not conducive to plant growth so that poor returns from crop cultivation discourages many farmers who have in many cases reverted to pastoralism.

CONCLUSION

This paper has reviewed some of the causes and reasons behind environmental degradation in the drylands of East Africa. The introduction of western technologies and ways of resource management in the name of development has disrupted the previously successful modes of resource utilization and resource management. Institutions considered necessary in the management of resources the western style, have created demands previously unknown in these lands so that over exploitation of other resources has occurred wherever water has been made easily accessible. Permanent water points have encouraged permanent settlements and intensive cultivation and intensive grazing of lands in these and in bordering areas to such settlements. Biomass harvesting to feed animals, to provide building timber and poles as well as animal enclosures have created open ecosystems in the East African drylands. Consequently, resources have been depleted in some places, land has been badly degraded to the extent that its productivity has been adversely affected thereby undermining the local

people's ability to cope and to meet the various demands facing them.

It has become necessary that the whole approach of developing these lands be re-examined. It is recommended therefore that participatory approach be employed so that the local people are given a say when it comes to identifying development projects. They be involved in the management of the projects as well. For the involvement to be successful, their cultures and traditions ought to be respected and incorporated into any project planned for these lands. The fragile nature of the ecosystems ought to be well understood so that any implemented project/undertaking does not adversely affect the environment. One fact that must always be taken into consideration is that the local people possess knowledge and adequate information on their lands. What is required therefore is to try and better the copying mechanisms which have successfully operated for many past decades.

REFERENCES

1. Ahmed, Y.J. & Kassas, M. (1987): Desertification: Financial Support for Biosphere. N.Y: UNEP. 1987.
2. Berry, S., Guyer, J., Peters, P., Issacman, A., Moore, A., Richard, A and Watts, M. (1983): The Food Crisis and Agrarian Change in Africa. Social Science Res. Centre, National Research Council, Washington, D.C.
3. Blaikie, P. and Brookfield, H.C. (1987): Land Degradation and Society. London. Longman.
4. Bromley, D.W. (1987): "Resources and Economic Development". Jour. Econ. Issues, Vol. XIX (3).
5. Bruntland Commission (1987): Our Common Future, World Commission on Environment and Development. N.Y. Oxford Univ. Press.
6. Chambers, R. (1983): Rural Development: Putting the last First. London, Longman.
7. Charney, E. (1975): "Dynamics of Deserts and Drought in the Sahel". Quately Jour. of Met. Society, Vol. 101. 1975.
8. Darkoh, M. B. K. (1990): Towards Sustainable Development of Kenya's Arid and Semi-arid Lands (ASAL). Kenyatta Univ. Public Lecture 1.
9. Dregne, H.E. (1983): Desertification of Arid Lands. Harwood Academic Publishers. N.Y. 1983
10. Ellis, J.E. and Swift, D.M. (1988): "Stability of African Pastoral Ecosystems: Alternative Paradigms and Implications for Development". Jour. of Range Management 4.1.6. 1988.
11. Finkel, M. and Darkoh, M. B. K. (1991): "Sustaining the Arid and Semi-arid lands (ASAL) Environment in Kenya Through Improved Pastoralism and Agriculture". Jour. of E.A. Research and Devel. Vol. 21. 1991.
12. Gufu, O. and Lusigi, W.J. (1987): "An Overview of Drought Strategies and Land Use in African Pastoral System". ODI Pastoral Dev. Network. London 1987.
13. Lusigi, W.J. (1981): Combating Desertification and Rehabilitating Degraded Production Systems in Northern Kenya. UNESCO-UNEP IPAL. Kenya.
14. Macleod, N.H. (1984): "Dust in the Sahel: Case of Drought" in Glantz, M.H. (ed.) Desertification Control, UNEP10, 1984.
15. Maghimbi, S. (1991): "The Riverside Maasai: Cattle Economy, Drought Settlement Pattern in the Pangani River Valley". Stone, J.C. (ed) (1991): Pastoral Economies in Africa and Long Term Responses to Drought. Aberdeen Univ. African Study Group. 1991.

16. Msangi, J. P. (1992): "Socio-cultural and Demographic Factors in Desertification Control in Kenya's Arid & Semi-arid Lands. Proceedings of the Workshop on Desertification Monitoring Assessment and Control Project. 1992.
17. ——— (1990): "Should There be Man-made Lakes in Africa?" D.F. Whigham, R.E. Good and J. Kuet (ed). Wetland Ecology and Management: Case Studies. Kluwer Academic Publications. 1990.
18. ——— (1987): "Conservation of Water Resources in the Semi-arid areas of Tanzania". Jour. of E.A. Res. & Devel. Vol. 17. 1987.
19. ——— (1982): "Water Resources Utilization in the Semi-arid Southern Zone of Tanzania". Water Supply and Management Journal. 1982.
20. ——— (1981): "Exploitation of Ground Water in Semi-arid Areas". Bulletin of Research & Information Vol. 1 No. 2. 1981.
21. National Environment Secretariat, World Resources Institute, Egerton University and Clark University (1990) Participatory Rural Appraisal Handbook: Conducting PRAs in Kenya. World Resources Institute, Washington D.C. USA. 1990.
22. Otieno (1993): "Resource Management and Its Implications to Desertification - Water Resources". Proceedings of the National Workshop to Formulate Kenya's Position in the Convention to Combat Desertification. Machakos. 1993.

ENVIRONMENTAL ISSUES IN RAIN WATER CATCHMENT SYSTEM

S H C de Silva¹

Abstract

Increasing demands on the finite surface water resources of the world sees no end in the foreseeable future with the growing world population.

The requirements of Irrigation will be under great stress in the efforts to increase production. Needs to feed industry, run electric generators and provide quality drinking water will all face grave threats specially in developing countries.

Managing the surface waters and ground waters have already reached some level of refinement. The yet untapped or under utilized Rain Water Cistern Systems gives much promise. The article raises the environmental issues to be faced in the development of this water resource.

Introduction

On the occasion of World Water Day, March 22nd, 1995 the Secretary General of the World Meteorological Organisation stated that by the end of this century water availability per inhabitant in Africa will be 5,100 cubic metres which is a quarter that of 1950. For Asia and South America the amount is 3,300 and 28,300 cubic metres respectively, which are one third of the 1950 values.

The above figures give the quota of water, per se, quantity wise, but quality wise, water fit for drinking is an entity that is under grave threat.

Managing Water Resources

Since available water resources in a country are finite, its management imposes a vital and crucial role.

Generally the Irrigation sector becomes the purveyor of the bulk of the country's resource and thus about 80% (Mistry 1992) of the total demand is taken by it, while drinking water is 5% whereas industry and energy is 15%. Economising use of water in Irrigation will give the best returns. Reducing losses in water supply net works and increasing efficiency of the

¹

Consultant, Teams Pvt. Ltd., P.O.Box 262, Colombo

hydro mechanical equipment reducing transmission losses all add up to the total saving of the precious water.

The ever growing scarcity of clean and fresh water is bound to increase the hardships faced by people in the developing countries.

The minimum average annual precipitation falling in Sri Lanka is 1000 mm on records extending to 30 years. This is about ten times that obtaining in an arid region like the Middle East. However in 1992/93 the Menik Ganga catchment received only 546 mm at Kataragama. Such rainless periods however alternate in the Dry Zone of the island, when surface reservoirs dry up and rivers reduce to a trickle.

The need for Rainfall Cistern Systems is therefore becoming increasingly felt with the short falls of rainfall and excess population pressure.

In developed countries, Rain Water Cistern Systems may only supplement public water systems but for a developing country it could be the only alternative specially in rural areas where ground water is unfit for human consumption, by salinity or ferrous contamination.

Development is a harbinger of rapid growth in urbanisation and conversion of agricultural lands to housing and factories. Concrete and asphalt paving promote fast run off of incident rainfall.

This in turn causes flash floods and severe soil erosion.

Urban areas cannot afford the luxury of large reservoirs as land is at a premium. In such circumstances roof catchment systems become a viable alternative as an important source of good quality water. It is surprising to realise the number of people who are unaware of this bonanza that falls as rain on their own roofs!

The international Drinking Water Supply and Sanitation decade (IDWSS) had spurred the jar programme in Thailand which resulted in 10 million 1-2 cubic metre jars and hundreds of thousands of 1-12 cubic metre jars. (Gould 1991)

The success of this jar programme is proof of its suitability in alleviating the problems faced by water scarcity.

Man has to devise solutions to alleviate suffering from floods during storms and store waters in time of scarcity.

Thus the American Islands, Guam, Marshall Islands and Micronesia which have no surface water, catch the rain and operate hydroponic farms to grow its vegetables.

Rain water cistern systems also act as partial flood retention areas though for limited duration.

Environmental Issues

Pollutants in atmosphere eg. falling dust, floating dust, nitric oxide, sulfur dioxide are absorbed and brought down by the rain.

Rain water receiving systems will therefore be transformed into banks or repositories of sediment, bird droppings, dust, windblown debris settling on roofs, rodents, crows, birds nests and other organic pollutants:

Wind borne seeds and bird droppings often germinate and give rise to plant growth on roofs and roof gutters.

Removal of pollutants have been ingeniously tried out by separation of the collecting waters. The first run off from a rainfall is led away to waste to avoid the surface wash of dust etc.

Thus in some Singapore high rise buildings the rainfall stored is used for flushing toilets.

This is a very wise use of collected rain water. According to Fewkes and Jay, 30% of potable water supplied to the domestic sector is used for water closet flushing. Use of treated expensive water for flushing is a criminal waste. The legislation brought about by U.K. water Act 1989, has changed the structure of the water supply industry and the method of charging water consumed. The feasibility for higher charge on metered water would be an incentive to use Rain Water Cistern Systems collection for flushing. Rain water cisterns on top of a building or at lower levels have potential for fire fighting and could claim lower insurance premium. As non structural measures these type of coercion have great promise.

Pollution

It is the bounden duty of the people of the land to safeguard the scarce water resources and also not pollute it while using. Polluted water leads to polluted streams and dead lakes and polluted ground waters.

In its first report since its foundation in 1993 the European Agency in Copenhagen listed ground water pollution as number 2 of the 12 most pressing environmental problems in 43 European countries. Two thirds of all Europeans depend on groundwater for drinking and other home use.

Roof and gutter Rainwater catchment systems are exposed to contamination from by their own surface itself. The roofing material itself eg. corrugated iron sheeting is subject to

corrosion with time. With asbestos roofing loose fibers result. Roofing in shanty towns are generally oil or tar barrel origin and rusted. To prevent roof sheets flying they are weighted by old tyres, which collect water and quickly become breeding grounds for mosquitoes that

can cause filaria, malaria or dengue fever. Most low income or middle class housing in Sri Lanka is roofed with Asbestos.

Wirojanagud (1991) cites Pathogenic contamination viz. salmonella in the samples in the Thailand study as well as heavy metals as Cd, Cr, Pb, Cu, Fe, Mn and Zinc.

He also found that first rainfall samples had higher contamination of the Mn and Zn and inferred that Mn and Zn leached first from galvanized iron roofing. Lye (1991) concluded that storage of rain water in cistern systems promoted growth of certain bacterial strains in numbers beyond that found in natural water sources.

With increasing pollution from vehicle exhausts and noxious plumes from industry the rain that can fall can be of high pH before it hits the roofs or the ground.

Hare Krishna (1989) in a U.S. Virgin Island Study concluded that 2/3 of 346 samples of cistern systems did not meet U.S. E.P.A. Standards and that bacterial contamination is more prevalent than contamination from heavy metals.

Atmospheric pollution is ever on the increase. In addition to man based pollution, the world's biosphere is being loaded with smoke and particulate matter from forest fires raging somewhere on the globe. Volcanic eruptions add massive dosages of toxic gases and volcanic ash that rise high into the stratosphere. Exhaust gases from aeroplanes emit their quota of carbon monoxide and sulfur dioxides daily.

Limited wars rage everyday in many countries round the globe adding to the global pollution as in Bosnia, Chechniya or Kurdistan where cities are raised to the ground by aerial bombardment or exploding shells.

The hundreds of oil wells that burned in Kuwait for years during and after the Gulf War have all contributed to the global warming pollution and the resulting ozone depletion.

The frantic search for new water resources can end up in the realisation that what was achieved by collecting rain water was water that was unfit to drink!

If cistern stored waters are to be used for drinking such waters need to be regularly monitored for quality.

Testing for pathogenies, bacteria, metals etc. necessitate costs, laboratory facilities and a dedicated technical staff all of which need recurring maintenance funding. Can developing countries with rising unemployment give priority to the health sector at the expense of creating more industry and creating more jobs?

A vicious cycle ensues. Opening new industries in a developing country, the sights are set for development. Reducing the pollution from such industry adds to the capital cost of the industry, which many a country will set aside for better times. This scenario is best illustrated from the abandoned projects in Romania, Czechoslovakia etc. where the dead trees stand sentinel to once thriving industrial complexes.

Environmental aspects of rain water harvesting whether by roof cisterns or ponds are therefore of the same magnitude as storing surface waters in large reservoirs. Symposiums as the International Conference on Rain Water Cistern Systems are a Messiah to developing countries to be aware of the problems and what mitigatory measures can be implemented to strive to get water for the health and well being of its citizens.

REFERENCES

- | | | |
|---------------------------------|------|---|
| Silva S H C de, | 1991 | Rain water harvesting, the constraints. Keelung, Taiwan, Proc. 5th I.C., R.W.C.S. P. 737 - 739 |
| Gould John E, | 1991 | Contribution of Rainwater Catchment System to I.D.W.S. & S.D., Proc. 5th ICRWCS, Keelung, Taiwan P. 23 - 31 |
| Krishna J. Hari, | 1989 | Cistern water systems in U.S., Virgin Islands, Proc. 4th I.C.RWCS Manila, Philippines |
| Wirojanagud W, | 1991 | Rainwater quality - Pathogens & Heavy metals. Proc. 5th ICRWCS Keelung, Taiwan P. 52 - 65 |
| Ichikawa M, | 1991 | Modernising Rain Water Cistern System in Tokyo. Proc. 5th ICRWCS Keelung Taiwan P. 144 |
| Obasi Prof. G O P, | 1995 | Message by Secretary General W.M.O. on World Water Day 22-03-1995 Int. Water & Sanitation Centre Hague, Netherlands |
| Fewkes A. Jay A | 1991 | Use of Rainwater for W.C. flushing in the U.K. Proc. 5th IRWCS Keelung Taiwan p. 511 |
| Mistry J F | 1992 | Planning of National Water Resources by applying New System of Water budgeting. Journal C.B.I & P, Delhi, India. |
| European Environmental - Agency | 1993 | First report E.E.A., Copenhagen Water Newsletter Nr.232 April 1995 |

Research on Rainfall Utilization for Water and Soil Conservation at Soil and Water Loss Region in Zhalantun, China

Mao Minghai

Heilongjiang Hydraulic Engineering College

(209 Xuefu Road, Harbin China P. C. 150086)

Abstract

The paper studies physical environment in zhalantun china. calculates soil and water loss areas by Heilongjiang province soil and water erosion equation. analyses causes of soil and water loss. Three measures of protecting soil and water loss through survey have put forward. These measures have yielded good results of ecology, economy and society.

Key words: soil and water conservation, soil and water loss, physical environment, soil and water erosion equation, small watershed

1 The general situation of physical environment

Zhalantun city lies on the south of Hulunbeiermeng in China. The total land areas are 16 926. 3km². It is located middle temperature zone continental half humid climate, the mean annual precipitation is 498. 2mm, most of it in 7~8

month, which account for 58.2% of mean annual precipitation, the mean annual temperature is 2.4 degrees, the mean annual evaporation loss is 1445.5mm.

The soil zonality in zhalantun belongs to black earth zone, it is stretched for west North-east Plain China black earth zone, because the majority of the region is hill and mountain, black earth is only distributed zone shape in hilly land and gentle slope or the foot of a mountain, which areas are small than black brown loam. South-east region is mostly hilly, topography is lower level, the black earth is distributed mostly. North-west in zhalantun is distributed brown loam and meadow soil. The soil vertical zonality in Zhalantun is simple, 900~1500m above sea level in mountains region is brown forest soil which vegetation is mostly taiga, 300~900m above sea level is brack brown loam which vegetation is mixed forest by broad-leaf and taiga, 250~500 above sea level in the foot of a mountain is black earth distributed belt and line shapes. In the foot of a hill the black earth links meadow soil in gully and marsh soil. In middle hill region, it is mostly distributed black brown loam, it is thin on slope but thick in lower slope. In gentle slope and the foot of a hill, it is less black earth, downwards meadow soil or marsh soil. In south-east mountain regain, the vegetation is mostly bush and grass which soil is black brown earth. Soil fertility in Zhalantun is organic fertilizer more than nitrogen(N) and phosphorus(P), the soil is middle or weak acid. Soil fertility distribution is west higher than east, north higher than south, natural soil higher than arable land.

Through survey in Lixing, Jianjagu, Xudiyingsi, Tuanjie, Gongjiain five small watersheds, it is shown: (1) Losing water, soil and fertility, let agriculture yield fall, because losing water, gentle slope change dryer, lowland ground temperature change lower, soil fertility can't effectively utilize. (2) Gullies in-

crease and arable lands subtract. According to survey in five small watersheds, the gully density is shown table 1, the ground gully erosion class is shown table 2.

Table 1 Modle small watersheds gully density

Small watershed	Lixing	Jianjagu	Xudiyingsi	Tuanjie	Gongjiajin
Gully density (km/km ²)	2.21	2.00	2.00	2.11	2.10

Table 2 Ground gully erosion class in Zhalantun

Gully erosion class	Gully density (km/km ²)	Gully % (account for total land)	Gully areas (km ²)
Light	<0.5	<1	71.20
Middle	0.5~0.8	1~5	112.75
Heavy	0.8~1.2	5~8	238.86
Extreme heavy	>1.2	>8	129.66

Survey is shown, there are 68 000 erosion gullies in zhalantun, which losed water, soil and soil fertility, to make up meadow land sand deposition and damage farm. Gully erosion land is 775 500 mu which account for 3.26% of total land. Gully erosion state is shown table 3.

Table 3 Gully erosion state in Zhalantun

Total erosion	Arable land	Arable land	Barren hill	Barren hill
Gullys		(mu/one gully)		(mu/one gully)
68 000	40 800	13.31	27 200	8.55

The freeze-thaw erosion in Zhalantun is reached 2 050.13 km². The freeze-thaw erosion combine with flowing surface water to make up erosion, so it is also distributed in water erosion region.

2 Soil and water loss calculation and its causes analyses

The soil erosion rate and soil and water loss areas calculated by Heilongjiang province soil and water erosion equation (Zhang Xiankui 1992). The equation is

$$A = RKLSCP$$

in the equation, R computer value is one rainfall erosion power (J/m²), the mean annual R is 84.945J/m²; K value is soil probability erosion factor, as to survey, the black earth is 0.26, black brown loam is 0.28; C value is ratio of some crop blocks soil loss quantity to no grass or fallow field blocks soil loss when crops are at the same conditions, as to survey and calculation, wheat is 0.0704, maize is 0.2578, soybean is 0.2626, millet is 0.2772, sorghum is 0.3295; P value is soil and water conservation measures factor, level terrace is 0.029, Diguan (Chinese, vegetation bamboo or twig fence) is 0.145, contour ridge plowing is 0.352, vegetation prevention belt is 0.372; L value is slope length factor; S value is slope factor; allowing for soil loss is 3~5/ha · a.

Combining Heilongjiang province soil erosion equation with data of water and soil conservation scientific research by many years fix place observation. In normal years, 3 degrees arable land, mean annual one mu lost $12\sim 15\text{m}^3$, 4 degrees lost $20\sim 30\text{m}^3$, mean annual erosion modulus is $5\ 230\ \text{T}/\text{km}^2$, nitrogens loss amount account for 29.15% of soil total nitrgen(N) output by water erosion, phosphorus (P) account for 54.96%, Potassium (K) account for 73.18%. The areas of soil and water loss account for 74.3% of total land areas. In loss areas, the light loss (surface soil layer denudation thickness is small than 20%) areas account for 44.6% of loss areas, middle loss (surface soil layer denudation thickness is $20\sim 60\%$) areas account for 15.3%, heavy loss (surface soil layer denudation thickness is more than 60%) areas account for 40.1%.

As to type of soil and water loss and soil and water loss branch region index, see table 4, the soil and water loss in Zhalantun townships can divide 4 branch regions.

Table 4 Soil and water loss branch region index
and its branch region in Zhalantun

Branch region	Stony middle-low mountains Slight erosion branch region	Stony low mountains Light erosion branch region	Stony soil hill Middle erosion branch region	Stony soil hill Heavy erosion branch region
Loss degree	mostly slight loss	mostly light loss	mostly middle loss	mostly heavy loss
Land areas (km ²)	7 120.4	4 510.3	3 675.0	1 620.8
Loss areas (km ²)	815.1	1 154.4	1 121.4	759.2

Erosion type (km ²)	Water erosion areas	815.1	1 154.4	1 121.4	759.2
	Freeze-thaw and water erosion areas	768.31	740.78	379.15	161.89
Soil erosion index	Soil class	mountain brown loam, brown forest soil	mountain black brown loam, black earth, meadow soil	black brown loam, black earth, meadow soil	black brown loam, black earth, meadow soil, marsh soil
	Erosion type	water erosion, freeze-thaw erosion	water erosion, freeze-thaw erosion	water erosion, freeze-thaw erosion	water erosion, freeze-thaw erosion
	One year denudation thickness (mm)	<0.16	0.12~2	2~4	4~6
	Erosion modulus (T/km ² ·a)	<200	200~2 500	2 500~5 000	5 000~8 000
	Gully density (km/km ²)	<0.5	0.5~0.8	0.8~1.2	>1.2
	Erosion scope (%)	11.45	25.59	30.51	46.84

Slight loss branch region: Chaihe, Haoraoshan, Elunchun;

Light loss branch region: Samajie, Haduohe, Wati, Halasu;

Middle loss branch region: Guanmenshan, Moguqi, Kutihe; Yaergen chum, Wudahaqi, Woniuhe, Dahwer;

Heavy loss branch region: Taipingchuan, Huifengchuan, Zhonghe, Moryniugou, Dahewan, Tuanjie, Zhalantun township, Chengjisihan.

3 Soil and waters loss causes analyses

- (1) Rainfall concentrate which some places are more rainstorm. In Zhalantun the mean annual precipitation is 485 mm, but rainfall of 7~8 month account for 53.9%, and more continuous rainfall, the daily maximum rainfall was reached 212mm in Moguqi township. The 33% of total precipitation make up erosion rainfall of soil and water loss.
- (2) There are more mountain and hill which account for 63.67% of total lands. If slope is 3~25 degrees, the soil erosion will be taken place by rainstorm and mountain torrents. The 7 degrees arable land soil loss is 6 times as long as 3 degrees slope arable land.
- (3) There are bad vegetation, soil layer of slope arable land is thin and loose. The slope arable land in agriculture region of east Zhalantun is little vegetation. As to data of hydrometric station in forest region, erosion modulus is small than $50 \text{ T/km}^2 \cdot \text{a}$ and just 1% of 6 degrees slope arable land in consequent slope land.
- (4) Black brown loam is more than other soil types in Zhalantun, but it is bad for resisting erosion which is easy erosion.
- (5) There are ever-frost. Because excessive cutting trees, the vegetation in forest region is damage, soil reliable quantity of heat equation is damage, freeze-thaw frequency change large, it let contain water quantity and volume weight change large, and increase soil unstability.
- (6) Because excessive cutting trees, the forewold is downwards 50km, so water erosion increase year by year.
- (7) In Zhalantu population increase more and more, and damage forest for cultivated soil, the new lands are more consequent ridges which are easy erosion.
- (8) In grassland there are excessive grazing and cultivating, increase areas of

erosion.

(9) Many stone and earth have been dug in Zhalantun for building, but it isn't soil and water conservation measures.

4 Utilizing rainfall for soil and water conservation measures

According to soil and water loss branch region and its causes, three measures of soil and water conservation have been put forward.

The first measure is foresting and grassing, sealing off gully for grassing, sealing off mountain passes for foresting, to increase vegetation and regulate surface runoff. The Slight loss and light loss branch region are located west low mountains region in Zhalantun, which are better vegetation, where sealing off mountain passes for foresting is main protecting measure of soil and water conservation. Middle loss and heavy loss branch region are located east Zhalantun, where is mostly agriculture region, in east Zhalantun many hilly are lands, so it is necessary for foresting and grassing and sealing off gully for grassing. Lixing and Jianjagu small watersheds have been planted soil and water conservation forests 2 541 mu. Trees are chosen by suit endemic, which grew in hillside bad soil by making level puddle, these trees are pine and sea buckthorn mixed forests. In the slope willows of fuel forest have been planted by digging cave, in sunshine slope better soil apple trees etc. of economic forests have been planted by making level terrace, in sunshine slope good lands have been planted speed-up forest by making level puddle. Combining arbor, shrub with fruit trees, foresting with protecting, intensive and meticulous farming.

The second measure is agriculture technology measures. It specially acts on heavy loss branch region where is mostly agriculture region. These measures are contour ridge plowing, increasing fertility for improving soil, fodder and crop ro-

tation, they can help soil absorb water, protect runoff concentration eroding, and utilize rainfall. Improving consequent slope ridge to contour ridge plowing, it can reduce 32~39% of runoff. Because topography change, the contour ridge is usually not at contours which have some slopes, if rainfall density is great, it will take place gully erosion. Basing on contour ridge, it conservates soil and water loss by slope farmland ridge farming. After shoveling grass, the soil reservations were made up at ridge gully contour to form small shallow holes. When the cross ridge slopes were from 1~4 degrees and the lengths of shallow holes were from 0.5~3.0m, the periods of concentration were 2~8 times longer and the runoff amounts were reduced by 17~70% compared with the original areas rainfall intensity of 3.6 mm/min.

Lixing and Jianjagu small watersheds have been planted 700 mu Digen vegetation belts. When slope runoff cross Digen vegetation belts, runoff speed change slow, mud and withered grasses stop at farmland under vegetation belts, which move upwards gradually as mud deposition to finally form vegetation terraces.

The economic forests were set up by level terrace which lengths are 3~5m, widths are 0.5~1m, the distances between level terraces are 2~3m, the level terrace edge made up soil reservation and arranged in triangle order.

In Lixing etc. small watersheds gentle slope farmland level forests were set up, which planted as contour, the distance of proportion between forests and width is 10:1. As to different topography, the distances between forest belt are 30~50m, It planted by clump form, the distances between clump and row are 0.7m.

Other agriculture technology for soil and water conservation are fish scale puddle, gully protecting forest. They have better effect for rainfall concentrated

and store up water.

The three measure is hydraulic engineering measures. In heavy erosion branch region, the gully density of some small watersheds are reached over $2.2\text{km}/\text{km}^2$. When administering erosion gully, hold rainfall ditches were set up at slope farmlands or contiguous areas of terrace and forest or lande, and at longer slope two ribs and some where slope change large or the foot of mountain slope which damage downwards farmlands. It can protect outwater to flow slope farmland or erode terrace. Combining storage water with small reservoir, they can act on adjusting flow by holding rainfall, reducing slow rainfall, storage rainfall, and discharging water etc. .

In the paper, data, tables and illustration have handled by PAM — GIS when I was a visiting professor studying in Canada. Basing on survey in Zhalantun, the Zhalantum hydraulic office provided some data.

Reference

- 1 Zhang Xiankue. 1992. Research on the soil erosion equation for Heilongjiang province. Harbin: Journal of Heilongjiang hydraulic engineering college, Vol. 19; 28

Fog Drip in California and its Implications for Cisterns

Robert J. Kourik, *TerraInforma & Associates*,
17200 Fitzpatrick Lane, Occidental, California 95465 USA

Abstract

The author compares ten years' worth of fog-drip measurements (taken in Northern coastal California beneath a 200-foot-tall Douglas fir tree, *Pseudotsuga Menziesii*) with measurements from a control rain gauge set in a nearby open meadow. For two years, the author measured fog drip every five feet from the trunk of this tree to its dripline as well as in a set of three gauges every five feet from the trunk of a second tree, an 85-foot-tall Douglas fir.

During the ten-year study, the fog-drip harvest under the 200-foot Douglas fir ranged from 155% to 312% of the year-round rainfall on the adjacent meadow. This paper summarizes the quantity of fog drip under two trees of different heights as well as at various distances from their trunks. The water collected under the taller tree averaged 12% less to 44% more than that under the shorter tree.

Finally, the paper examines the potential for recharging a properly located cistern with an inverted collecting-roof built beneath trees in areas with seasonal fog.

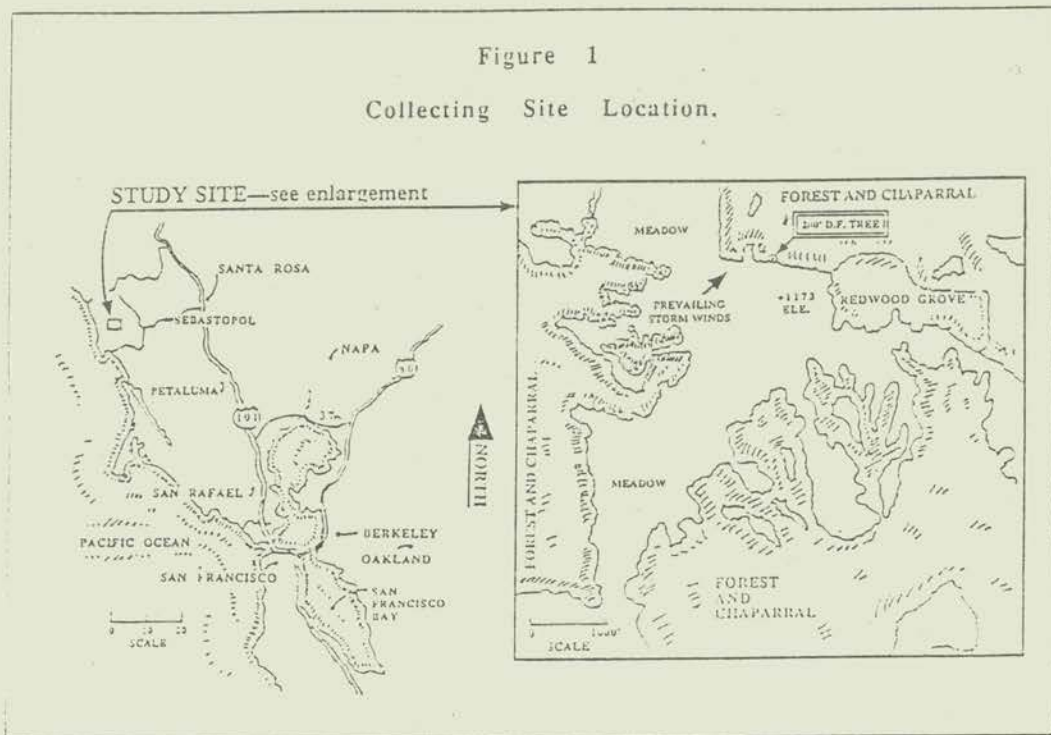
Introduction

In areas with the proper topography, trees, elevation and fog, moist air can condense to form fog drip like a steady rain. Fog drip has been studied throughout the world in various Mediterranean climates (Ellis 1971, Oberlander 1956, Means 1927, Moral and Muller 1969, Jacobs et al. 1985, Hamilton and Rowe 1949); semi-desert and desert climates (Louw and Seely 1980, Vogelmann 1973, Ingraham and Matthews 1988); humid temperate climates (Ingwersen 1985, Vogelmann et al. 1968, Azevedo and Morgan 1974, Jagels 1991, Trautner and Eiden 1988, Green and Jane 1983, Dollard and Unsworth 1983, Shuttleworth 1977, Harr 1982, Ellis 1971); and subtropical climates (Ellis 1971, Juvik and Ekern 1978, McKnight and Juvik 1975, Vogelmann 1973). Researchers have also monitored the accumulation of condensed fog beneath various trees and shrubs (Vogelmann et al. 1968, Azevedo and Morgan 1974, Oberlander 1956, Byers 1953, Means 1927, Harr 1982, Vogelmann 1973, Hamilton and Rowe 1949). All of these studies have found a wide range of enhanced precipitation beneath the studied trees.

This study and paper are an attempt to address three important deficiencies in the literature: (A) No studies have measured fog drip under the same trees for extended periods of time. (B) In the literature surveyed by this author, not one researcher has documented the different rates of precipitation under one tree at various intervals out from the trunk. And, (C) the implication of fog drip for cistern catchment and recharge has been noticeably ignored.

Site Description

The collecting site is located 85 miles north of San Francisco, California (See Figure 1.) on a ridge running East to West, with vegetation composed of open grazing grasslands and mixed oak/Douglas fir/Coastal redwood forests. (Mostly *Pseudotsuga Menziesii* and *Sequoia sempervirens* with California live oak [*Quercus agrifolia*] and



California black oak, [*Q. Kelloggii*]). The woodlands contain scattered virgin Douglas fir trees up to 4 1/2 feet in diameter (DBH) and over 200 feet tall.

The climate is Mediterranean, with an average annual rainfall of 54.08 inches, most of which falls in the winter between October and April. Summer rainfall is low to nonexistent.

The tallest tree at the site is a Douglas fir, shown in cross-section view in Figure 2 as Tree #1. It is approximately 200 feet tall, with a 56-foot-wide canopy, and stands 100-175 feet above all but one other tree in the forest's border, well-positioned to intercept the prevailing weather.

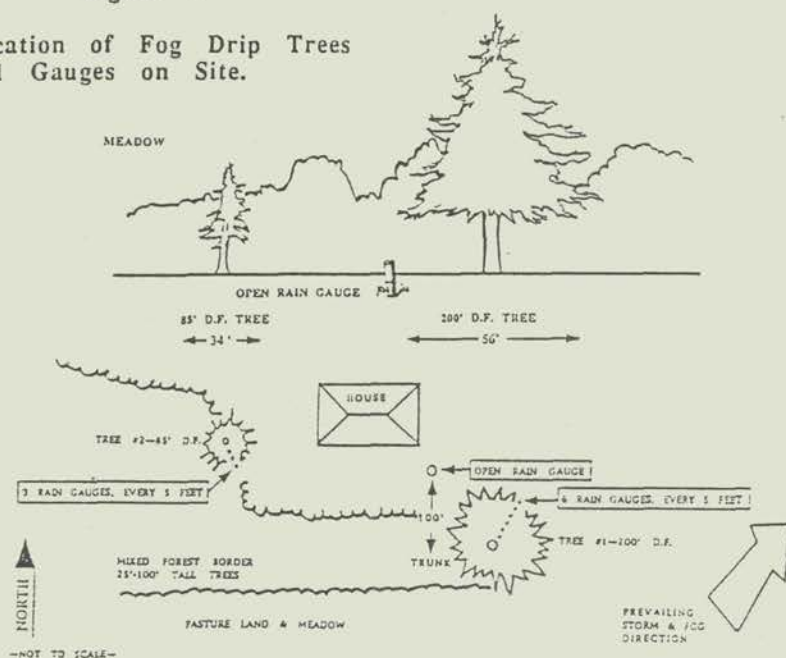
The second tree monitored, Tree #2 (Figure 2), was chosen for the study because, at 85 feet tall, it is about 67% shorter than Tree #1.

Methods

The intent of this study was to set up a monitoring program that could be easily and inexpensively replicated by the average homeowner. To that end, no expensive or complicated meteorological equipment was used.

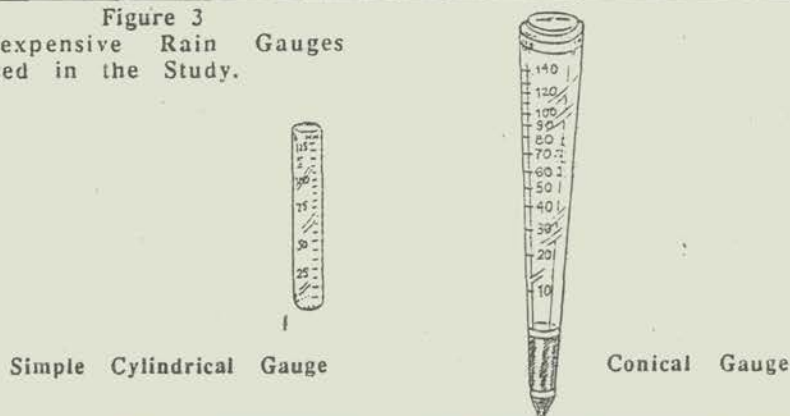
Figure 2

Location of Fog Drip Trees and Gauges on Site.



Two primary conical rain gauges (See Figure 3), each with a capacity of 5.5 inches, were installed in 1985, one located about 19 feet from the trunk of the 200-foot tree and the other in an adjacent meadow. For the subsequent study of fog drip at various intervals beneath the canopy, eight simple and inexpensive (\$3 US) tube-type gauges, each with a five-inch capacity (measured in 1/10-inch intervals), were used.

Figure 3
Inexpensive Rain Gauges
Used in the Study.



The longest phase in this study, which began ten years ago, measured fog drip with conical gauges in two locations only: beneath the 200-foot tree and in the nearby open meadow. Beginning in 1985, the conical-gauge measurements of fog drip were taken 19 feet from the trunk of Tree #1 at an arbitrary location chosen for convenience. The conical gauge for the open-sky measurements taken in the same period is located in the meadow 100 feet to the North-Northeast of the tree-canopy fog-drip gauge. The ten years of fog drip and rain measurements for tree #1 are summed up in Figure 4. (Due to illness or travel there are no data in Figure 4 for the equivalent of 18 months out of the ten-year study.)

The second phase of measurements began in 1992. This separate set of data was done concurrently with the monitoring of the two original conical rain gauges. During the two-year period, and continuing to the present, simple cylindrical gauges were placed every five feet out from the trunk of Tree #1 to the dripline of the foliage, and three cylindrical rain gauges on three-foot stakes were added every five feet out from the trunk of Tree #2. These records are discussed later.

All rainfall records are tabulated from September 1st through August 31st of each 12-month period.

Results

During ten years of study of fog drip under the 200-foot-tall Douglas fir (DF) tree there were 19 summer months when there was no measurable rain in the open-sky (OS) gauge but measurable precipitation beneath the tree. During 15 months of the survey, there were no measurements in either the OS or DF gauges during the dry summers.

In general, the DF gauge captured more water than the OS gauge, even during rain events during the winter rainy season. (See Figure 4.) There were, however,

Figure 4

Comparing Open Sky Rain to Fog Drip Harvest
Beneath a 200-Foot Douglas Fir Tree.

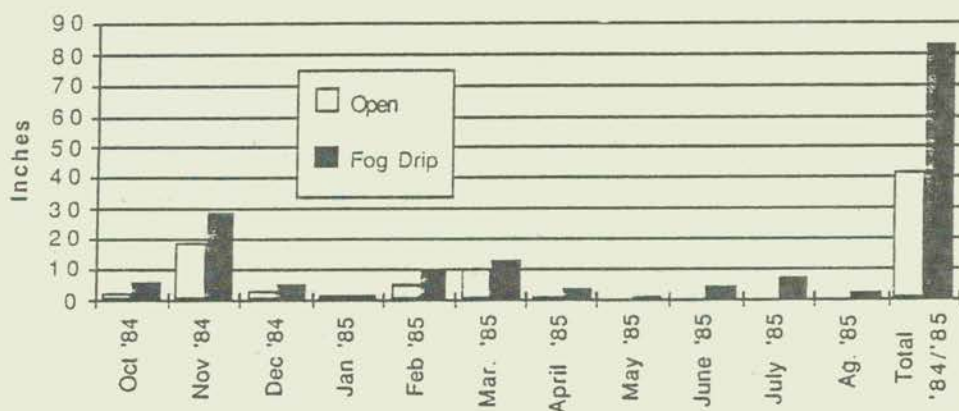


Figure 4, cont.

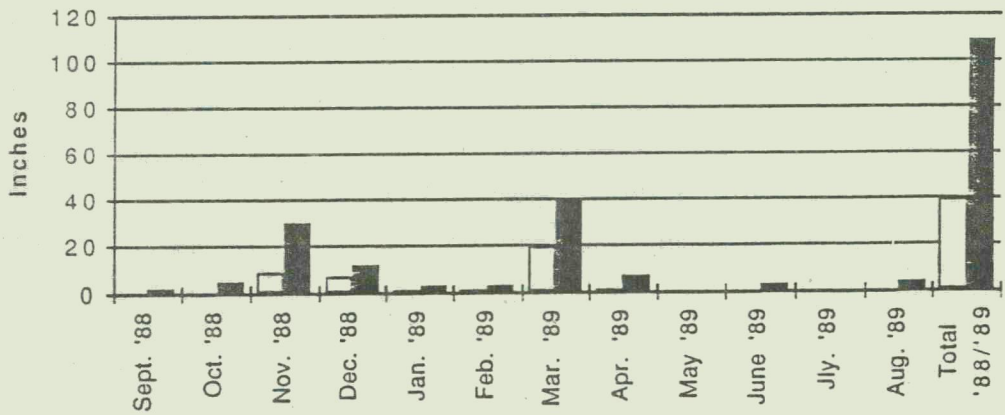
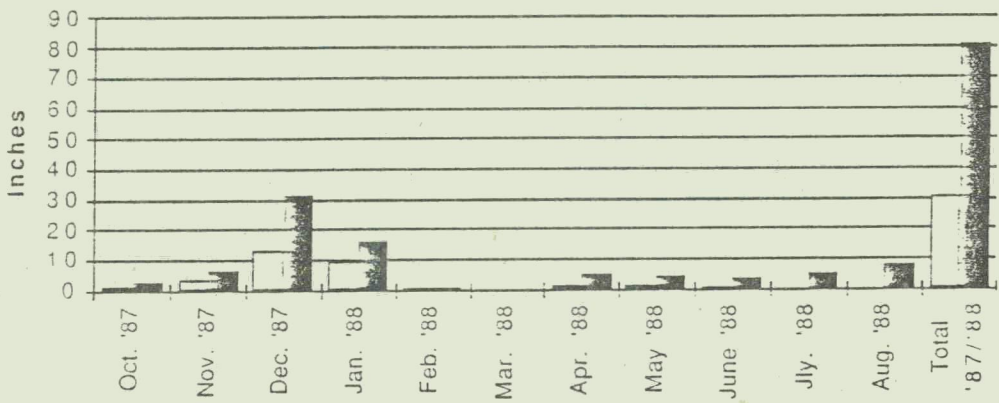
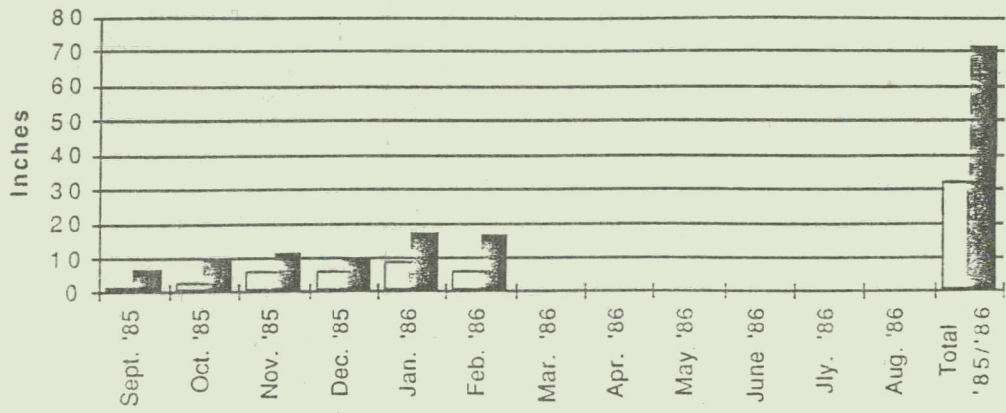


Figure 4, cont.

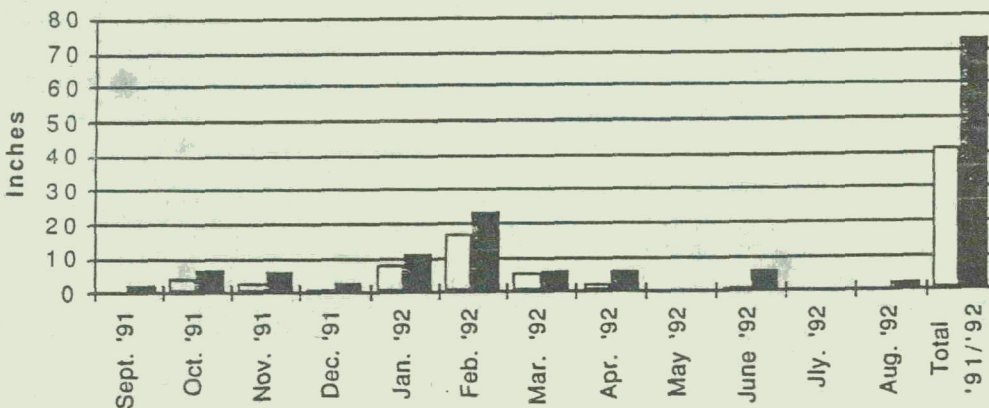
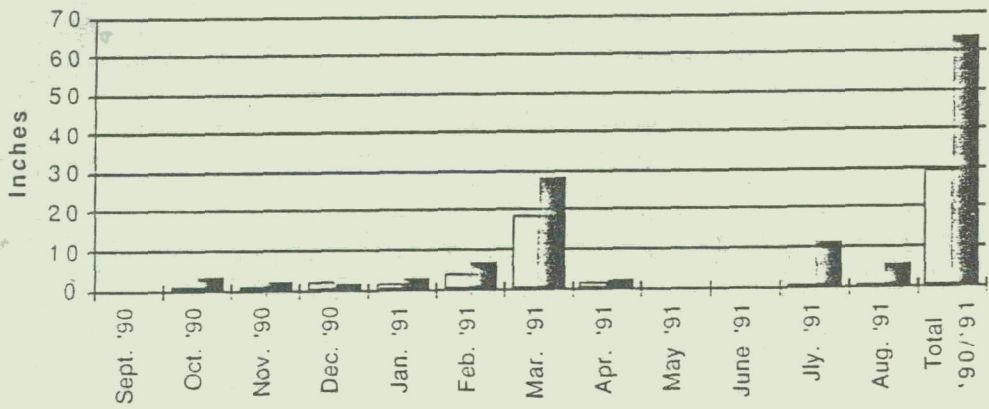
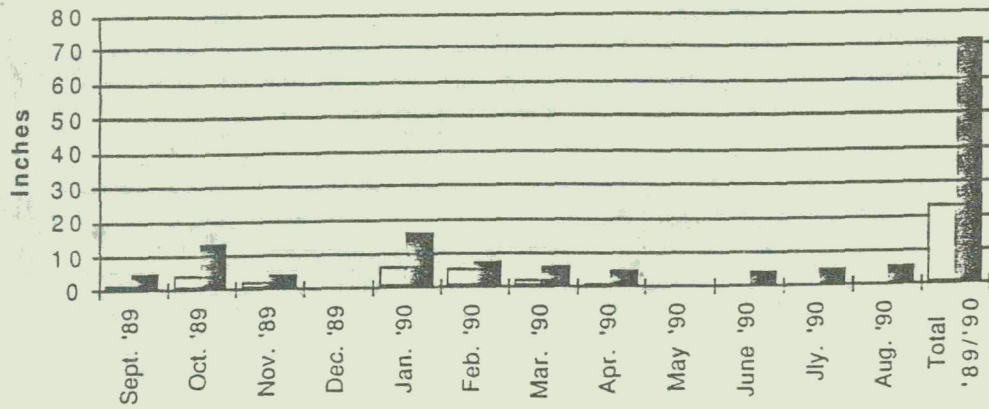
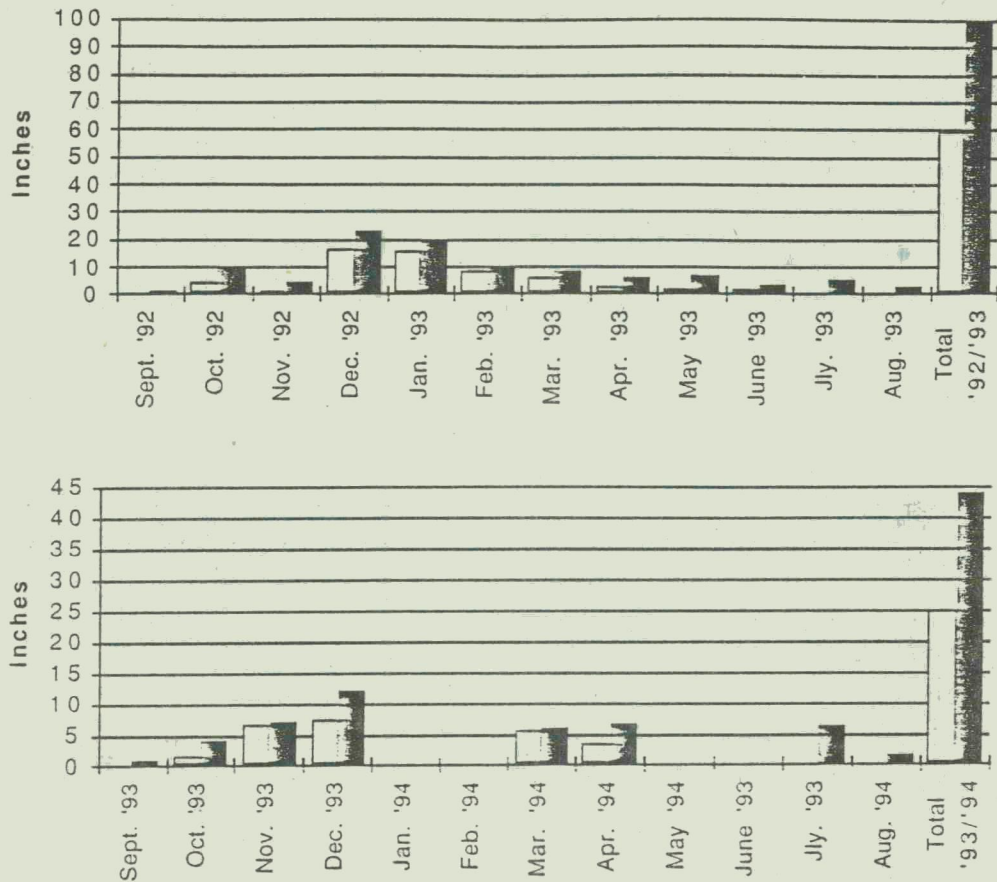


Figure 4, cont.



extreme variances between individual months. The lowest ratio between the DF and OS gauges for a month was a negative 22% difference for December 1990 (OS = 1.84", DF = 1.45"). The only other month where the DF gauge had less water than the OS gauge was January 1985, with the open gauge collecting 1% more water than the DF gauge (OS = 1.7", DF = 1.68"). This was presumably due to some difference in the type of fog or the dew point, or influenced by either the level or the movement of the fog events.

There were 99 months where the DF gauge captured more water than the OS gauge. The three most notable months were: August 1991 at 4583% (OS = .12", DF = 5.5"), July 1991 at 5650% (OS = .2", DF = 11.3") and May 1985 at 8000% (OS = .01", DF = .8"). See Table 1 for details. Table 1 also shows that the highest measurable winter fog-and-rain harvest beneath the DF tree was 29.55 inches for the month of November 1988, during a protracted six-year drought. The lowest recorded monthly summer fog harvest for the DF tree was .8 inches during May 1985.

The annual ratio between the DF and OS gauges varied from a low of 1.67 in the 1992/1993 rain season, or 167% more water in the DF gauge, to the highest recorded

Table 1
Comparing Rain to Fog Drip Under a 200-Foot Douglas Fir Tree.

Month	Total	Open	DF	Cumulative Total for	Ratio
			Open Gauge	DF Gauge	DF/OS
Sept. '91	1.88	3.38			2.30
Oct. '91	18.77	28.92	20.75	14.48	1.54
Nov. '91	2.74	3.28	23.49	19.74	1.93
Dec. '91	1.7	1.88	25.19	41.42	0.99
Jan. '92	5.23	2.68	30.52	51.08	1.81
Feb. '92	9.91	12.94	40.43	88.04	1.31
Mar. '92	0.9	1.98	41.03	47.99	0.58
Apr. '92	2.81	3.4	43.24	88.73	10.00
May '92	3.1	4.27	44.14	73.08	12.70
June '92	0	7.4	44.14	80.48	2.00**
July '92	0	2.14	44.14	10.5	0.00
Total 1991/92			44.14	92.6	2.01
Sept. '92	1.45	4.58	45	1.55	4.54
Oct. '92	3.03	12.24	4.48	8.92	1.38
Nov. '92	1.9	11.1	15.28	27.02	1.58
Dec. '92	4.1	10.3	14.48	28.22	1.59
Jan. '93	9.05	17.05	25.52	55.27	1.88
Feb. '93	4.25	18.4	31.78	71.87	2.52
Mar. '93	NA	NA	NA	NA	NA
Apr. '93	NA	NA	NA	NA	NA
May '93	NA	NA	NA	NA	NA
June '93	NA	NA	NA	NA	NA
July '93	NA	NA	NA	NA	NA
Aug. '93	NA	NA	31.78	71.87	NA
Total 1992/93			31.78	71.87	2.26
*No records back to through Aug. 93					
Sept. '93	0	0	0		
Oct. '93	2.15	2.75	2.15	2.75	1.28
Nov. '93	1.8	4.4	3.75	2.15	1.73
Dec. '93	12.83	13.0	15.58	10.05	2.41
Jan. '94	3.07	15.75	27.55	15.8	1.78
Feb. '94	0.55	0.4	28.2	18.8	1.49
Mar. '94	1	1	28.2	18.8	0.00
Apr. '94	1.3	4.5	28.5	41.1	2.49
May '94	1.4	1.2	12.9	45	2.73
June '94	3.18	1.45	11.08	48.45	5.17
July '94	3	10.05	31.08	71.5	3.00
Aug. '94	2	7.84	31.08	11.14	0.00
Total 1993/94			31.08	11.14	2.81
Sept. '94	2	2.75	31.08	2.35	0.00
Oct. '94	1	4.4	31.08	4.85	0.00
Nov. '94	4.35	29.55	17.43	18.4	1.14
Dec. '94	1.1	11.8	47.92	48	1.15
Jan. '95	1.2	2.8	49.12	17.8	2.33
Feb. '95	1.55	1.2	44.48	14	1.14
March '95	19.45	12.1	18.93	23.1	2.01
Apr. '95	1.05	1.5	49.98	100.8	1.14
May '95	3	3	49.98	100.8	2.00
June '95	3	3.8	49.98	104.2	3.00
July '95	0	0	49.98	104.2	0.00
Aug. '95	3	4.38	49.98	108.58	0.00
Total 1994/95			49.98	108.58	1.55
Sept. '95	1.8	4.7	1.8	4.7	2.94
Oct. '95	4.15	13.5	3.75	18.2	3.25
Nov. '95	2.1	4.3	7.85	22.5	2.05
Dec. '95	0	0	7.85	22.5	0.00
Jan. '96	8.25	13.7	14.2	18.2	2.47
Feb. '96	5.25	7.3	19.45	43.5	1.39
March '96	2.3	4.1	21.75	51.6	2.55
Apr. '96	1.07	5.1	22.82	56.7	4.77
May '96	0	0	22.82	56.7	0.00
June '96	0	4	22.82	60.7	0.00
July '96	0	5	22.82	45.7	0.00
Aug. '96	2	1.5	22.82	11.2	0.00
Total 1995/96			22.82	71.2	3.12
Sept. '96	0	0	0	0	0.00
Oct. '96	0.87	3.3	0.87	3.3	4.93
Nov. '96	0.7	2.2	1.37	3.3	3.14
Dec. '96	1.88	1.48	3.22	8.85	0.78
Jan. '97	1.89	2.8	4.87	8.85	1.78
Feb. '97	4	4.3	8.87	18.23	1.63
March '97	18.4	28.35	27.27	44.7	1.54
Apr. '97	1.73	3	29.02	46.7	1.14
May '97	0	0	29.02	46.7	0.00
June '97	0	0	29.02	46.7	0.00
July '97	0.2	11.3	29.02	58	58.60
Aug. '97	0.18	3.8	29.34	43.8	45.83
Total 1996/97			29.34	43.8	2.16

Table 1, cont.

Sept. '91	5	2.1	0	2.1	0.00
Oct. '91	4.2	4.5	4.2	8.6	1.51
Nov. '91	3	5.8	7.3	14.4	1.93
Dec. '91	0.5	3	7.8	17.4	6.00
Jan. '92	7.7	15.9	15.8	28.3	1.40
Feb. '92	18.9	23.25	22.3	31.45	1.38
March '92	5.3	4.3	37.8	37.55	1.19
Apr. '92	2.2	4.2	4.0	64.25	2.86
May '92	0	0	4.0	64.25	0.00
June '92	1.15	8.3	41.15	70.55	5.48
July '92	0	0	41.15	70.55	0.00
Aug. '92	0	7.8	41.15	73.05	0.00
Total 191/92			41.15	73.05	1.78
Sept. '92	0	0.84	0	0.84	0.00
Oct. '92	4.2	9.38	4.2	10.20	2.23
Nov. '92	1.65	4.25	5.85	14.54	2.93
Dec. '92	16.35	23.08	22	37.62	1.41
Jan. '93	15.98	18.68	37.98	56.3	1.17
Feb. '93	5.1	9.9	48.08	48.2	1.22
March '93	6.2	1.2	52.28	74.4	1.32
Apr. '93	3	8.1	35.28	30.8	2.03
May '93	1.68	6.65	17.28	47.45	3.51
June '93	2.4	1.9	59.64	41.35	1.53
July '93	0	1.25	59.64	48.6	0.00
Aug. '93	0	3.2	59.64	48.8	0.00
Total 192/93			59.64	49.8	1.67
Sept. '93	0	0.8	0	0.8	0.00
Oct. '93	1.65	4	1.65	4.8	2.42
Nov. '93	6.75	6.6	4.4	11.7	1.02
Dec. '93	7.51	11.65	15.91	23.45	1.54
Jan. '94	0	0	15.91	23.65	0.00
Feb. '94	3	0	15.91	23.65	0.00
March '94	5.91	5.8	21.42	29.45	1.05
Apr. '94	1.25	4.7	24.77	34.15	2.02
May '94	0	0	24.77	34.15	0.00
June '94	1	0	24.77	34.15	0.00
July '94	0	4.2	24.77	42.25	0.00
Aug. '94	0	1.75	24.77	44.1	0.00
Total 193/94			24.77	44.1	1.73

* 0.1 inch (2.54 mm) or less is rounded up to 0.1 inch (2.54 mm) and 0.1 inch (2.54 mm) or more is rounded up to 0.2 inch (5.08 mm).

† 0.1 inch (2.54 mm) or less is rounded up to 0.1 inch (2.54 mm) and 0.1 inch (2.54 mm) or more is rounded up to 0.2 inch (5.08 mm).

‡ 0.1 inch (2.54 mm) or less is rounded up to 0.1 inch (2.54 mm) and 0.1 inch (2.54 mm) or more is rounded up to 0.2 inch (5.08 mm).

yearly ratio of 3.12, or 312% more DF precipitation as compared to the open meadow for the 1989/1990 rain year. The arithmetic mean of DF-precipitated water was 225% greater than that measured in the open rain gauge during the ten years of record-keeping.

The records comparing the original 200-foot tree with an 85-foot tree (See Figure 5.) show some marked differences: (A) the taller tree harvested considerably more water, averaging 36-44% more total precipitated water than the smaller tree, and (B) the quantity of water varied depending upon the distance from the trunk. The taller tree precipitated the greatest amount of water at a location approximately 68% of the distance from the trunk to the dripline.

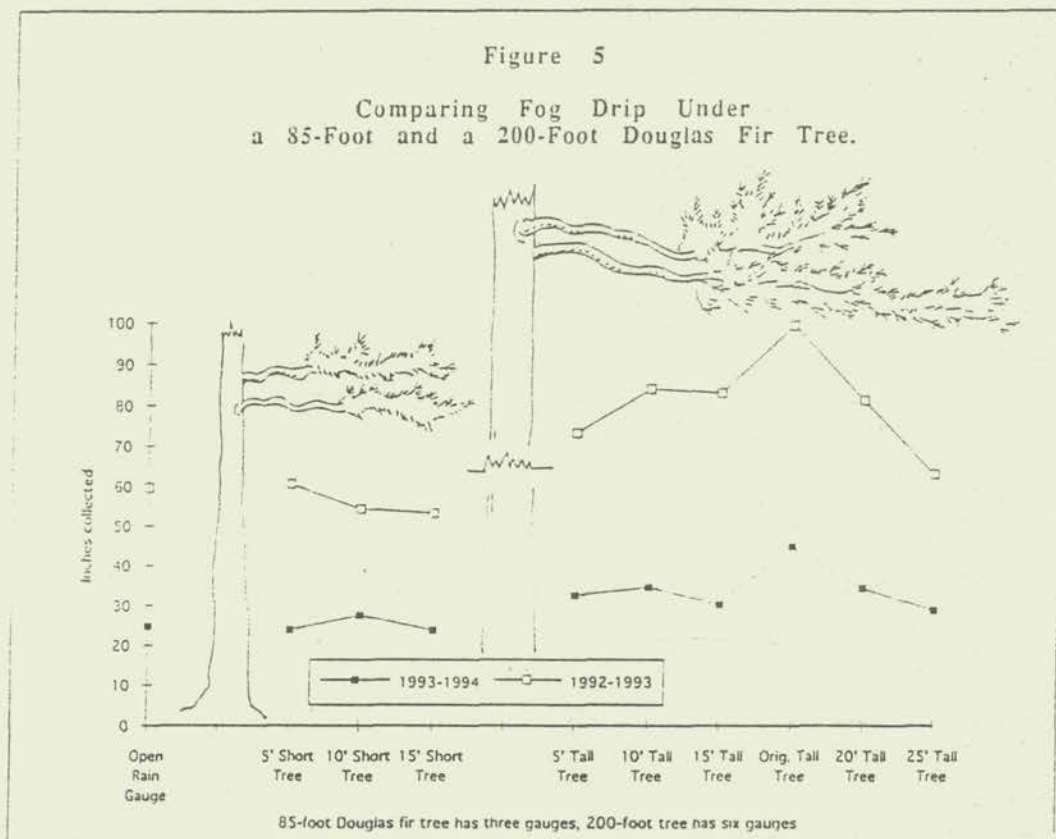
In Figure 5, measurements taken from the tallest tree chart approximately the same pattern and indicate proportionally nearly equal amounts of captured water relative to the distance from the trunk. For the 1993/1994 and 1992/1993 seasons, the highest recorded amount was 36.6% greater than the lowest amount of captured fog drip, which was collected in a gauge 25 feet from the trunk.

With the shorter tree, the 1992/1993 season showed 12.2% more water at the gauge located five feet from the trunk than in the gauge at the edge of the canopy. In that season, the gauge at the five-foot distance was the only one to capture more water than the gauge in the open meadow. During the 1993/1994 season, the gauge at the 10-foot distance from the trunk gathered 13.5% more water than any other gauge, however, no gauge located beneath the tree in that year captured a greater amount of water than the conical rain gauge located in the open meadow.

Discussion

Since Northern California has a typical Mediterranean climate with dry, nearly rainless summers; the productive use of fog drip can be a valuable resource for non-potable-water use. Since the inflow to a cistern from a catchment area beneath a tall tree which directly intercepts fog and rain events can be considerable, the author proposes that fog drip can be a valuable resource to maintain cistern storage levels for landscaping, irrigation, clothes-washing, toilet-flushing and showering and to reduce demand on wells or municipal water supplies.

This study, and the work of others (Azevedo 1974, Oberlander 1956, Means 1927), indicate that a collecting site should be carefully surveyed for ideal placement of

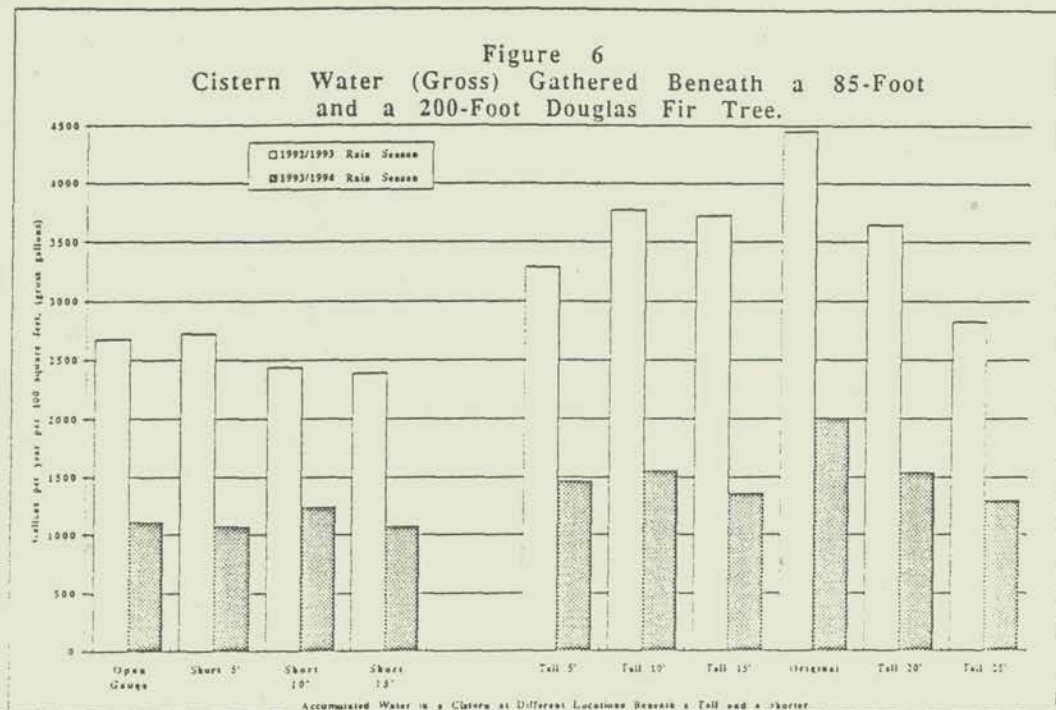


monitoring rain gauges, and that the most potential for fog-drip harvest occurs with conifer trees, especially those which are: (A) close to the edge of a forest-and-meadow interface, (B) tall enough to intercept fogs and lower clouds (C) wide with a large foliage mass, and (D) growing where fogs are frequent and heavy.

Rain-gauge measurements should precede any construction of catchment surface. The rather wide range of total drip-water from various locations beneath the studied trees would indicate that as many rain gauges as possible should be placed at various intervals and radii from the trunk. (Even the six rain gauges placed along one radius in this study may not have collected representative data, since it demonstrates that

the amount of water collected under a single tree can vary by at least 36.6% depending upon gauge location.)

During this study, the total summer fog-harvest (in the 19 months during which only fog drip was collected) averaged 3.91 inches per month. For every 100 square feet of conical cistern roof the gross water would be a total of 244 gallons per month (or 1220 total gross gallons per five-month summer) or 878 gallons per summer, assuming a 28% loss. Figure 6, with a .72 adjustment factor, shows the actual amounts



of water, in gallons per year, harvested relative to the position under both Tree #1 (tall) and Tree #2 (shorter).

The best solution for many situations may be to integrate a cistern, its roof and the catchment surface into one structure built at the point of greatest measured fog drip. An inverted, semi-conical roof can cover a cistern and simultaneously act as the catchment area. (See Figure 7; note that the conical catchment is screened to keep debris and animals out of the cistern.) This combination rain and fog-drip cistern is especially useful in much of the California coastal zone because the rainless summers are so long that few people can afford to build a cistern big enough to store enough water from winter rains to last for the entire summer.

The amount of fog drip to be collected by a catchment area constitutes a considerable amount of water. According to other cistern researchers (Mickelson 1977, Pereira O. J. et al. 1983, Irwin 1977) the gross amount collected is adjusted by .56 to .72, or a 44-28% loss, for the practical net harvest of a sheet-metal catchment area.

Those considering cistern construction might also wish to determine how such construction might affect native plants in the vicinity. In order to determine how much harvested fog-water be collected without harming native plants, it is necessary

Figure 7
A Freestanding Cistern with a Conical Collecting Roof.



to compare the amount of fog drip to the plants' evapotranspiration rate (ET_o). (See Table 2.) For May through September of the original ten-year study, the average of

Table 2
Comparing Evapotranspiration Rates to Harvested Fog Drip.

DAILY COASTAL EVAPOTRANSPIRATION RATES (ET _o) BY MONTH AND FOG HARVEST											
Total Average Monthly Fog Drip Harvest Over Ten Years, in inches per month											
Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.**
9.5	8.57	11.87	4.68	1.29	2.84	3.21	3.01	1.67	5.02	6.8	6.49
Monthly ET _o Rates, in inches per month											
Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.***
1.46	1.32	2.44	2.95	3.66	4.61	4.88	4.76	4.13	2.81	1.3	0.73
Fog Drip Harvest Adjusted to ET _o , in inches											
Jan.	Feb.	March	April	May*	June*	July*	Aug.*	Sept.*	Oct.	Nov.	Dec.
6.5068	6.4924	4.8648	1.5864	0.3525	0.6161	0.6578	0.6324	0.4044	1.7865	5.2308	8.8904
* - Less than 0.0 equals a deficit (not enough fog drip to satisfy the total ET _o); greater than 0.0 is a surplus of fog water relative to the ET _o .											
** = Total Yearly ET _o , in inches = 35.05											
*** = Total Yearly Fog Drip Harvest, in inches = 38.02											

fog-drip water harvested, in inches, is equal to less than the ETo rate for optimal plant growth, and ranges from 35% to 65% less water than ideal irrigation requirements. (These figures are based on an ETo of 1.0-or 100%-for cool-season lawn grasses. Many drought-resistant plants can thrive on an ETo considerably less than 1.0). During the rainy season, the amount of fog drip/rain harvested far exceeds that of the ETo, from 1.79 inches more in October to as much as 8.89 inches more in December. In this case, all native plants in the forest could be maintained at an optimum moisture level and surplus water could be captured for storage in a cistern to supplement summer landscape irrigation. On a yearly basis, the fog-water harvest exceeds the ETo rate by 2.97 inches. Thus, it appears that one may be able to capture nearly three inches of fog-water without depleting the forest's reserve of moisture.

Summary

Fog drip has previously only been studied as an ecological phenomenon related to forest growth (Azevedo and Morgan 1974, Ellis 1971, Ingwersen 1985, Oberlander 1956, Byers 1953, Means 1927, Green and Jane 1983, Harr 1982, Vogelmann 1973). This study shows that the monthly and annual fog drip beneath Douglas fir trees is indeed significant, as the combined rain and fog drip measured in the study amounted to up to 3.12 times more water than could be collected by rain gauges located in an adjacent open field.

This preliminary work also shows the importance of taking interval measurements beneath the tree canopy for an accurate understanding both of the total amount of water gathered and of its proportion relative to the distance from the trunk. The highest fog-drip measurement under the 200-foot Douglas fir, taken at a 19-foot distance from the trunk, was 36.6% greater than the lowest measurement, taken at the edge of the canopy. Thus, measuring at various intervals and radii for fog precipitation is essential to proper location of a cistern-catchment area.

Coastal fog drip in a Mediterranean climate offers a partial or full solution to the dilemma of dependence on cisterns in regions of seasonal rainfall. When rains are infrequent or almost nonexistent for a part of each year, fog-drip harvesting can supplement dwindling supplies of stored winter rain, allowing for smaller cistern size.

Furthermore, fog drip is, in some "rainless" locations, sufficiently greater than the ETo of the native landscape so that existing plant moisture needs can be met and surplus water can be gathered for cistern storage. In this study, 2.97 inches of fog drip per square foot of catchment could be stored each year, probably without any adverse impacts on the needs of the native flora.

Literature Cited

- Azevedo, J., Morgan, D. L. 1974. Fog Precipitation in Coastal California Forests. *Ecology*, 55 (5), pg. 1135-1141.
- Byers, H. R. 1953. Coast Redwoods and Fog Drip. *Ecology*, 34 (1): 192-103.
- Dollard, G. J., Unsworth, M. H. 1983. Field Measurements of Turbulent Fluxes of Wind-Driven Fog Droplets to a Grass Surface. *Atmospheric Environment*, 17 (4): 775-780.

- Green, T. G. A., Jane, G. T. 1983. Diurnal Patterns of Water Potential in the Evergreen Cloud Forests of the Kaimai Ranges, North Island, New Zealand. *New Zealand Journal of Botany*, 21 (4): 379-389.
- Hamilton, E. L., Rowe, P. B. 1949. Rainfall Interception by Chaparral in California. California Forest and Range Experiment Station, US Forest Service: 5-33.
- Harr, R. D. 1982. Fog Drip in the Bull Run Municipal Watershed, Oregon. *Water Resources Bulletin*, 18 (5): 785-789.
- Ingwersen, J. B. 1985. Fog Drip, water yield and timber harvesting in the Bull Run Municipal Watershed, OR. *Water Resources Bulletin*, American Water Resources Assoc., Vol. 21 (3): 469-473.
- Ingraham, N. L., Matthews, R. A. 1988. Fog Drip as a Source of Groundwater Recharge in Northern Kenya. *Water Resources Research*, 24 (8): 1406-1410.
- Irwin, R. W. 1977. Cistern for Domestic Water Use. *Canadian Agricultural Engineering*, 19 (1): 12-14.
- Jacobs, D. J., Cole, D. W., McBride, J. R. 1985. Fire History and Perpetuation of Natural Coast Redwood Ecosystems. *Journal of Forestry*, 83 (8): 494-497.
- Jagels, R. 1991. Biophysical Aspects of Fog Deposition on the Needles of Three Conifers. *Journal of Experimental Botany*, 42 (239): 757-763.
- Juvik, J. O., Ekern, P. C. 1978. A Climatology of Mountain Fog on Mauna Loa, Hawaii Island. Water Resources Research Center, U. of Hawaii, HI, Technical Report #118. 63 pgs.
- Louw, G. N., Seely, M. K. 1980. Exploitation of Fog Water by a Perennial Namib Dune Grass, *Stipagotis sabulicola*. *South African Journal of Science*, 76 (1): 38-39.
- Means, T. H. 1927. Fog Precipitation by Trees. *Science*, Vol. LXVI No. 1713: 402-403.
- McKnight, J. H., Juvik, J. O. 1975. Methodology Approaches in Hawaiian Fog Research. Project Partial Completion Report for Fog Precipitation Along Topo-Climatic Gradients on the Island of Hawaii. Technical Report #85, 25 pgs.
- Mickelson, R. H. 1977. Performance and Durability of Sheet Metal, Butyl Rubber, Asphalt Roofing, and Bentonite for Harvesting Precipitation. In *Proceedings of the Water Harvesting Symposium*, Phoenix: AZ, March 26-28, 1977; Agricultural Research Service, USDA, ARS W-22: 93-102.
- Moral, R. del, Muller, C. H. 1969. Fog Drip: a mechanism of toxin transport from *Eucalyptus globulus*. *Bulletin of the Torrey Botanical Club*, 96 (4): 467-475.
- Oberlander, G. T. 1956. Summer Fog Precipitation on the San Francisco Peninsula. *Ecology*, 37 (4): 851-852.
- Pereira O. J., Paiva, J. B., Andrade, E. M. 1983. Yield of Rainwater Harvesting Using Tile Roofs. (Spanish with English Summary.) *Cien Agon., Fortaleza, Federal de Ceara*, 14 (1/2): 91-96.

- Shuttleworth, W. J. 1977. The Exchange of Wind-Driven Fog and Mist Between Vegetation and the Atmosphere. *Boundary-Layer Meteorology*, 12 (4): 463-489.
- Trautner, F., Eiden, R. 1988. A Measuring Device to Quantify Deposition of Fogwater and Ionic Input by Fog on Small Spruce Trees. *Trees: Structure and Function*, Springer-Verlag, #2: 92-95.
- Vogelmann, H. W., Siccama, T., Leedy, D., Ovitt, D. C. 1968. Precipitation from Fog Moisture in the Green Mountains of Vermont. *Ecology*, 49 (6): 1205-1207.
- Vogelmann, H. W. 1973. Fog precipitation in the Cloud Forests of Eastern Mexico. *BioScience*, 23 (2): 96-100.

ENVIRONMENTAL CONTRIBUTIONS OF SOME TRADITIONAL TECHNIQUES

Nirmal Sengupta¹

[This paper discusses the positive effects of some traditional irrigation and water harvesting systems of India towards salinity control. Some of these, like the khadin of western India are still surviving. Currently some studies are available which describe how the system survived for hundreds of years in spite of being located in a highly salinity prone tract. Other traditional system like in north India, have been replaced by modern techniques. In their case it is only possible to document the past conflict between farmers and irrigation agencies on this issue and also that certain recent recommendations for salinity control establish the correctness of the old approach. Important lessons may be learnt from studying these traditional systems.]

INTRODUCTION

As per the last estimate, the extent of salt-affected soils in India was 7 million hectares. By now it has probably increased to about 10 mill. ha. (Abrol and Dhruva Narayana ed., 1990 : 307). This however, is the area with acute salinity. The magnitude of the problem is far more severe and a much larger part of canal irrigated areas run the risk of turning saline. Bowonder and Ravi (1984) had estimated that 10 million ha of land in the country are waterlogged and about 25 million ha suffer from soil salinity. Kanwar's estimate of areas suffering from different degrees of salinity is about 20 million hectares. It is estimated that the productivity, in nearly 50 per cent of the area under canal irrigation has been adversely affected in varying degrees due to problems of waterlogging and salinity (Abrol, 1992 : 67).

Three broad types have been identified (Mamoria, 1980 : 148-149 ; Abrol and Dhruva Narayana ed., 1990 : 319) as salinity prone.

(1) The western part of India is a semi-arid to arid region with hot climate and a dry winter. In this climate evaporation is always greater than precipitation. Hence the soil profile development by eluviation is greatly retarded. The soil is marked by concentration of salts - saline and alkaline. Estimated salt affected area is about one mill. hectares.

(2) The marked seasonality of rainfall effects salt release over a very large part of the country. In south India and the Gangetic valley warm rainy climate is followed by dry winter. During the rainy season precipitation is greater than evaporation which

¹ Professor, Madras Institute of Development Studies, 79, Second Main Road Gandhinagar, Madras, India - 600 020. Paper presented to Seventh International Conference of the International Rainwater catchment Systems Association, Beijing, June 19-25, 1995

induces leaching of soluble salts down the profile. If the water table remains high, the soluble salts will remain in the profile. In northern India, in particular, the salts are transported in solution by the Himalayan rivers which later percolate in the sub-soils of the plains and goes on accumulating in the area of inefficient surface drainage. Thereafter, during the dry season these salts are drawn upwards through the capillary spaces by evaporation from the surface. In many cases salts are deposited on the soil surface showing white or black patches of efflorescence on the soil surface. Impervious sub-soil or hard pan also contributes to the phenomenon. Estimated salt-affected area is about four million hectares, 2.5 in Indo-Gangetic Plains and 1.42 in the Medium and Deep Black Soil Regions of central and southern India.

(3) A very large part of coastal region, about two million hectares, are affected by sea tide carrying salt laden deposits. The river deltas and estuaries of the eastern coast accounts for about 1.4 mill. ha. of salt affected areas. Another 0.7 mill. ha. is found in the arid Gujarat coast. Large parts of sea coast are also subjected to periodic inundation by tidal water. This is particularly noted in the western coast.

In dealing with problems of salinity two types of solutions are possible: preventive and curative. Current stress is on curative methods. These include: (1) chemical treatment, (2) vegetative and biological measures and (3) a combination of the two. The former is input intensive but results are obtained in the first year. The latter needs 3 to 4 years gestation period. In forty years, till 1989-90 the state of Uttar Pradesh was able to reclaim 157,036 ha. of land which accounts for only 12 per cent of the total saline area in the state (Arora, 1994). With increasing alarm lately, programmes have been accelerated. Since gypsum is available in abundance in Rajasthan state, neighbouring the Indo-Gangetic saline belt, and since the State governments subsidise it heavily (in Haryana, subsidy is 75 per cent of cost) farmers often adopt the chemical treatment. But is it a sustainable solution? Newer and newer areas will come under salinity and more and more of these costly and heavily subsidised activities will have to be performed.

That is why the long-term preventive solutions are important. Preventive efforts require thorough understanding of the reason and preventing it. It is here that the traditional method of maintaining the ecological balance for centuries, will be of great relevance even in the present period. In the next sections we will introduce the outlines of some of these traditional methods and discuss the soundness of their scientific principles.

PREVENTIVE AND CURATIVE USES OF RAINWATER

However pure irrigation water is, it always contains some salt. Salts are added to the soil with each irrigation. Crops remove much of the applied water from the soil to meet its evapotranspiration demand but leaves most of the salt behind. At each irrigation more salt is added. Hence a portion of the added salt must be leached from the root zone before the concentration affects crop yield. Leaching is done by applying sufficient water so that a portion percolates through and below the entire root zone carrying with it a portion of the accumulated salts. After many successive irrigations, the salt accumulation in the soil will approach some equilibrium concentration (FAO, 1985). A successful water management is to keep the equilibrium level within a certain limit which is best for crop growth.

This equilibrium level is decided by three factors (FAO, 1985) :

- (i) the salinity of the applied water
- (ii) depth of water leached below the root zone
- (iii) depth of water applied at the surface

A good salinity management strategy should take care of all the three factors. Apart from the low salinity of rainwater the application methods of different rainwater harvesting systems contribute towards determining the equilibrium level of salt content.

The quality of river waters in India, unless contaminated otherwise, are of a very high order (Gupta, 1990 : 19-26). Canal waters originating from the rivers or their reservoirs as the main source, represent the parent rivers in quality, unless contaminated otherwise. Yet, however good may canal water be as leaching agent,

Table - 1

AVERAGE ANNUAL RAINFALL IN SALT AFFECTED AREAS

regions	annual rainfall (in cms.)
Indo-Gangetic Plains :	
(i) alkali soils with sweet groundwater	55-100
(ii) alkali soils with sodic groundwater	50-55
(iii) saline soils with moderately saline groundwater	100-140
Medium and deep black soil region :	
(iv) alkali soils with sodic or saline groundwater	70-100
Arid and semi-arid region :	
(v) saline soils with highly saline groundwater	below 50
Coastal areas :	
(a) arid zone of Gujarat	below 30
(b) deltaic (1) W.Bengal, Orissa, (2) A.P. , Tamilnadu	140-160 70-90
(c) sea water ingress, e.g.Kerala	200-300
INDIA AVERAGE	113

source : Abrol and Dhruva Narayana ed. , 1990 : 309-310

rainwater is certainly the best. Composition varies as one moves away from the sea, depending on local pollution sources and from shower to shower. But overall, the rainwater has an EC range between 5 to 50 $\mu\text{S cm}^{-1}$ (Gupta, 1990 : 16) compared to some 200-300 $\mu\text{S cm}^{-1}$ common in canal water. Thus the equilibrium concentration of salt accumulation in the soil attained after many successive irrigations, is lower if the leaching agent is rainwater in comparison to use of canal water. For partial leaching to attain tolerable limits for crop growth, less amount of water is necessary if the leaching agent is rainwater, not canal water. This in turn, contributes to the reduction in problems of waterlogging in areas having drainage problems.

Gupta (1990 : 264-273) made some rough estimates of salt balance and leaching requirements. He found that in monsoon countries, when the rainfall is short and concentrated, rainwater may be sufficient to leach out salts from the root zone. Without going into the details let me draw attention to the rule of thumb that he developed. "The depth of soil from which the soluble salts (> 80 per cent of it) may be leached during the monsoon season, corresponds roughly with total rainfall during the monsoon season" (Gupta, 1990 : 270). Thus, if the root zone depth of the soil is 40 cm. from which accumulated salts are intended to be leached, a minimum amount of rainfall equal to 40 cm. is necessary. The actual requirement will vary depending on the texture of the soil and other percolation considerations. Still, this gives an idea. The following are the average annual rainfall of the salinity prone areas of India (Table -1) . It must be evident that rainwater is available in plenty for effecting high proportion of leaching almost everywhere in India.

While discussing suitable strategies for using saline water for irrigation Gupta (1990 : 270) had favoured maximum utilisation of rainwater for two reasons :

- (i) it has a modifying effect on the number of irrigations required to meet the evaporative demand as part of it is met by rainfall, and
- (ii) it helps in leaching of accumulated salts, because it is the best quality water available for leaching.

A close look at these two principles will establish that they are valid not merely for the limited objective Gupta had set for himself, but in general too. Because of these considerations, maximum utilisation of rainwater must be the most desirable strategy for salinity control. Indeed, this was so in the traditional set up. Colonialism and modern extension programmes had failed to grasp these principles and had done enormous damage to the agricultural land. Even now, it is necessary to honour these principles. We will discuss some traditional techniques of India from this perspective.

INDO-GANGETIC PLAINS

If water influx in the substratum is greater than water expenditure [$I > Q$] then the groundwater level increases and waterlogging occurs. The water influx in this area is very high because of heavy annual rainfall and an enormous amount of snowfall carried by the Himalayan rivers flowing through this region. The first priority therefore, is to drain out the excess water. The traditional method facilitated drainage - both by horizontal and vertical methods. The natural drainage lines were never interfered with, leave alone directing them inland through canals. Besides, the

major mode of irrigation was wells, which provided vertical drainage. Fortunately, most parts of this region has sweet groundwater.

Natural precipitation was retained (Whitcombe, 1971 : 6) in water harvesting structures like tanks and ponds (called *jhils* - surface depressions filled by summer rains). The *jhils* were reported to supply some amount of irrigation water and produced forage (Stone, 1984 : 140). Indirectly too, they must have contributed significantly by enriching subsoil moisture. Recharging of groundwater was an important factor. Although rainfall is high in this region it is highly variable and irrigation is absolutely essential during summer and drought. Finally, the tanks and ponds ensured the supply of the best leaching agent, rainwater, in this salinity-prone area. Canal construction techniques were not unknown but rarely used. The best known canal is the Western Jamuna canal constructed in the sixteenth century by the Delhi Sultanate, probably imitating west Asian models. The canal had fallen into disuse and had inspired the British engineers to undertake canal construction.

Nineteenth century construction of canals and distributaries in U.P. did not follow the watersheds and interfered considerably with natural drainage lines. The railways and roadways too had no consideration for the drainage systems (Stone, 1984 : 134-135). But the need was felt badly after occurrence of severe floods, waterlogging, salinity and malaria in canal irrigated tracts of U.P. As the problems of salinity aggravated investigations began. By late 1860s causes were known and a couple of experimental leaching and drainage stations were established. However, the results were not encouraging. A Committee (Reh Committee, 1878) was appointed whose report reflects the unassailable contradictions faced by the government (Whitcombe, 1971 : 76-79 ; 285-289). The Committee could not admit what was clearly evident from all available information -- that introduction of canal irrigation itself was the basic mistake. For heavy water influx the Committee laid the blame on the farmers' practice of overirrigation, suggested raising of water rates to achieve greater economy of water and recommended continuation of the reclamation experiments. The Reh Committee had also recommended, albeit reluctantly, that lift irrigation should be substituted for flush irrigation. In order to open the market the Canal Department had earlier offered flush irrigation at lower rates than the existing lift irrigation (Whitcombe, 1971 : 9). Gravity irrigation from canal was touted as replacement for the dreary old water lifting (Whitcombe, 1971 : 78). So it was a reluctant admission. In any case, the government could not further raise the already high water rates. This had set the course of salinity control efforts. The leaching and drainage experiments, though unsatisfactory, became the only implementable policy. The preventive efforts could extend only that far, not up to a fundamental reconsideration of canal policies.

The old rainwater harvesting systems could not survive the pressure of canal irrigation. The interference with the natural drainage systems wrecked havoc on them. Stone (1984 : 135) describes a case where the original system used to drain flood water into a rivulet after flowing through two *jhils*. After the construction of a canal, within a few years the water levels of the *jhils* increased inundating surrounding land, throwing them out of the cultivable category. After the drainage channels were dug, numerous complaints were made by farmers that the drainage system was drying out the country excessively. Often their canal supplies were diminished. Besides, the *jhils* etc. which stored rainwater were rendered dry for about nine months a year (Stone, 1984 : 140). Indeed, it was so excessive that watertable of places thirty miles away, fell. Some twenty years later, following serious drought, when tubewell irrigation was being considered, some officers felt that the policy of surface drainage has been carried too

far. The subsoil water level is lower than it was twenty years ago and have a permanent tendency to fall (Stone, 1984 : 141). Following destruction of rainwater harvesting structures canal irrigation remained the only source of recharging groundwater. Wherever canals went, well-digging was often made impracticable by the rise in the water table. So the farmers had little choice but to adopt canal water (Voelcker, 1893 : 69 ; Whitcombe, 1971 : 80-81). Table -2 shows the extent of destruction of rainwater harvesting structures as reflected in official statistics. The data about them are included under two heads ; 'tanks' and 'other sources'. We have grouped them together. The choice of the two years are guided by data availability and comparability of district boundaries before administrative reorganisations.

Table-2

Changes in Irrigation pattern between 1901 and 1974
Some districts of present Uttar Pradesh (U.P.)

Addition in land use between 1901 and 1974 (in '00 hectares)									
Irrigated							Net Sown Area		
District	Tank Other Sources	Canal	Total Surf. Water	Tube Well	Total Ground Water	Tot. Irr. Land	Tot. Unirr. Land	Actual	As if addn.
Sara banvi	-414	610	196	-322	724	5	300	-105	-55
Sitapur	-149	594	445	-285	374	98	544	-500	-37
Rae Bareilly	-227	352	125	-516	171	-345	19	357	376
Unao	-216	803	592	-488	183	-306	287	-37	248
Lucknow	-132	385	253	-169	157	-11	242	-258	-27
Basti	-350	188	-163	-332	1269	937	774	-272	502
Jaunpur	-102	106	4	-350	585	235	239	165	404
Allahabad	-270	429	158	-350	707	357	515	-63	453
Budaun	-71	0	-71	385	891	1276	1205	-1128	66
Barreilly	-112	44	328	96	305	400	728	-638	91
Comparison is difficult due to addition in net sown area:									
Mainpuri	-68	217	179	-272	1045	773	652	-463	490
Pilibhit	-128	392	265	-138	374	236	500	16	516
Fatepur	-219	290	71	-41	261	220	291	306	597
Azamgarh	-523	336	-118	-672	1205	532	345	774	1118
Kheri	-96	147	51	-146	512	366	417	430	847
Sultanpur	-259	436	176	-287	296	8	185	376	561
Partabgarh	-284	430	146	-341	96	-245	-99	548	449

Source : Indian Agricultural Statistics, Govt. of India.

Large scale implementation of drainage programme in U.P. began only since the 1880s, when a series of wet seasons created serious waterlogging problems and prompted an outcry against canals (Stone, 1984 : 139). By 1900 the aggregate surface drainage channels constructed were more than a third of the total length of canals and distributaries (Stone, 1984 : 134-145). The old irrigated areas settled to new equilibrium levels after several years. Later, after the introduction of tubewells and power operated pumpsets vertical drainage too has been a possibility. These have solved a part of the problem, but only a part. As yet, little has been done to provide proper drainage in canal irrigated areas. The problem continues and the threat of waterlogging and salinity becomes more and more acute.

CENTRAL AND WESTERN REGION

Salinity is also found in large parts of Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Rajasthan and Andhra Pradesh. The soil characteristics here differ from that of the Indo-Gangetic pattern which need different set of considerations. Both saline and alkali soils are found depending on the aridity of the region. But we need not distinguish between them, for, our concern is prevention of salt deposits in any form. In leaching of salt content one has to consider that the soils of this region in general, have slow water infiltration and percolation rates and water diffusivity. Substantial part of this region consists of medium and deep black soil (vertisols) which tend to have a positive water balance fluctuating between shallow depths. Any additional salt carried in by canal water tend to accumulate. Since digging, laying and maintaining is difficult in this soil the scope of drainage is limited. Groundwater is sodic or saline and therefore, vertical drainage possibilities are also ruled out. Because of slow water diffusivity, soil degradation process in this region is slow. Only as time passes and in complete absence of leaching, salt content increases sizably in the surface horizon. But once it appears it is difficult to get rid of. Projects like Nagarjunasagar and Sriramsagar in Andhra Pradesh, Tungabhadra in Karnataka, Tawa in M.P. and Indira Gandhi canal in Rajasthan are only some of the major ones which are suffering from salinity problem.

The traditional system that was extensively used until some three decades back was that of "submergence tanks". This is basically *in situ* water harvesting. The undulating topography allows for the construction of above-surface tanks. Although gravity irrigation may be performed that was rarely practised in the black soil region. The *Bundhies* or submergence tanks retained water practically throughout the rainy season. After the rainy season water used to be drained out and the bed was used for cultivation. Sometimes river floods were diverted to feed the submergence tanks. They consisted of embankments with heights neither as great as the above-surface tanks nor as low as field boundaries. Submergence tanks did not provide gravity irrigation. Instead, the bed, rich in subsoil moisture, was cultivated. They also need to be distinguished from *in situ* storage. In one, cultivation follows submergence and drainage, in the other they occur simultaneously (Sengupta, 1993).

Submergence techniques were basically conservation of moisture by contour bunding in the water-shed itself. Storage of fresh rainwater for months over the whole watershed could effect some amount of leaching. This was the perfect answer to extremely slow water infiltration and percolation properties of the soil. At the same time the admirable water-retention capacity of the soil was used to devise a more

efficient method of water utilisation than gravity irrigation. Submerging also helped in soil conservation. The concerned area is prone to severe soil erosion.

Until a couple of decades back, the submergence technique was extensive all over the *haveli* tract of M.P. A century ago it was found all over the western region. Reference to the *sailabi* system of Punjab is found in old official records. It is still a recognised system of irrigation in Baluchistan where it is known as the *sailaba* system (Oesterbaan, 1983). Although the system might have covered, at a rough estimate, a million hectare or more, and had at one time, received government patronage, recent information regarding them are not found in official irrigation statistics in India. Surprising though it may appear, the reasons for this omission are not within the scope of this paper (Sengupta, 1993 : 27-29). In essence, the reluctance to consider rainwater harvesting structures as irrigation, is at the root of such ignorance.

Recently, one submergence irrigation structure, found in the midst of Thar desert and called *khadin*, have drawn considerable attention. The *khadins* of Rajasthan, though provide surface irrigation in years of good rainfall, are utilised primarily for subsoil storage properties. *Khadins* are found even in the heart of Thar desert. The old *khadins* have been found to be site-specific systems. The soils of *khadins* are medium to fine in texture, with good water-holding characteristics as against the loose, sandy, droughty soils of the rest of the desert. These soils remain wet or moist for a long period, and are favourable for chemical weathering of soil minerals and for microbial activities. The temporary water table that is formed in *khadins* after collecting precipitation over the catchment area, slowly recedes into the subsoil and substrata during winter, thus continuously supplying moisture to the deep growing roots of the crops throughout its period of growth. Depending on the good or bad rainfall in a year either gravity irrigation or bed cultivation is practised in a *khadin*. It is reported that *khadins* succeed in producing at least one crop even if the rainfall in a year is one-third that of normal.

The amount of run-off collected in a *khadin* depends on the extent of the catchment area, which is about 12 to 15 times that of the service area (Kolarkar and Singh, 1990). The region being a particularly saline tract, the rainwater harvest would contain some salt by leaching out their wider catchments. In course of time the salt will accumulate in the profile and turn the land unusable. *Khadins* however, have remained functional for several centuries. Intrigued by this fact, the soil scientists of Central Arid Zone Research Institute have conducted on this system one of the rare studies of salinity control in traditional systems. They (Singh and Kolarkar, 1983) show that there is not much salt accumulation inside the *khadin*, but heavy deposits are found just outside where water from seepage passes out. Obviously, the incoming salts are continuously expelled. Their explanation is that the sediments accumulating inside the *khadin* gradually raise the bed level. It reaches in old *khadins* between 0.25 to 1.00 metre. In consequence, the hydrostatic pressure of water body of *khadins* push the salt content out, which deposits on the outer side of the embankment.

COASTAL REGIONS

Saline soils of delta and coastal regions include Ganga delta or Sunderban, Mahanadi, Godavari, Krishna, Cauvery and small river deltas in the east coast and the estuaries of Narmada and Tapi in the west. Here, both prolonged waterlogging and sea water

intrusion create problems of salinity. Besides deltas and estuaries marine cycles also affect sea water ingression in many coastal areas. These include the lagoons of Kerala, *khar*, *khajan* and *kole* lands of western coast extending from Gujarat to Kerala and the Rann of Kutch. In the east coast, salinity due to sea water ingression is less, but saline delta regions abound.

In general, in these areas horizontal drainage is not possible. Saline water ingress need to be prevented first by constructing sluice gates and protective embankments. Thereafter salts present on the surface can be flushed out with good quality water. Fortunately once again, most parts have good quality water. Rainfall is generally very high (above 140 cm) in the specific regions or on the hills nearby as in the western coast. In the past rainwater used to be stored in shallow ponds within protective embankments. This system of cultivation of rice was extensive in West Bengal (*bheris*), Orissa, in *kharland*, *khazan* and *kole* cultivation in the west coast. In the modern phase too the same principle is being followed with improved structures.

The southern part of the east coast and the Kutch peninsula are the only coastal regions not favoured by heavy rainfall. In these deficient rainfall regions the groundwater too is saline. But the salinity of the coastal soil is so high that the river water is good enough for sufficient leaching. In the low rainfall regions of Krishna or Cauvery delta, with good river water supply, canal irrigation used to be practised extensively in the past. It is only in these parts of the country that canal irrigation had developed extensively even in the pre-colonial period.

Data shows that in Kutch and Saurashtra region there were thousands of small tanks in the past. Whether this was one of the purpose of those tanks can be decided only after knowing their exact locations - which is beyond the capability of the present author.

CONCLUSION

It is neither possible nor desirable to go back to the pre-modern situation by writing off the networks of canals and other structures. But the traditional principle of using rainwater as much as possible is also confirmed by modern research. Along with drainage, embankments or long duration storage wherever necessary, these principles need to be resurrected in order to find a sustainable solution to the everwidening problems of salinity. This imply a thorough reappraisal of irrigation system design. However daunting it may seem, irrigation technology today needs thorough reappraisal from many aspects other than that of civil engineering.

Rainwater harvesting systems have mostly been seen as small scale or "minor irrigation" systems - as per Indian terminology. Seen in the above perspective, they are not. The well-laid network of tanks and ponds in the Indo-Gangetic plains used to share between them, the whole of the run-off flowing through each watershed. Submergence tanks used to be constructed in series and they could appropriate every bit of run-off after a flood in the adjacent rivulet. The coastal ponds would not be successful unless a whole series checks sea water ingression along a long stretch of coastline. When appreciated from this perspective the whole design will seem to be a major irrigation system. Indeed, this is a kind of design which has the potential to compete with modern multipurpose river valley projects. They deserve to be developed along this line.

REFERENCES :

- Abrol, I. P. and Dhruva Narayana, V. V. ed. 1990 : Technologies for Wasteland Development, Indian Council of Agricultural Research, New Delhi
- Abrol, I.P. 1992 : "Towards Sustainable Use of Our Soil Resources", in Growth of Indian Agriculture : Issues and Policies , Deptt. of Economics and Sociology, Punjab Agriculture University
- Arora, Hema 1994 : "Some Emerging Issues in Usar Reclamation", Wasteland News, New Delhi, Feb-April
- Bowonder, B. and C. Ravi 1984 : "Waterlogging from Irrigation Projects : An Environmental Management Problem" , Centre for Energy and Technology, Administrative Staff College of India, Hyderabad, unpublished
- F.A.O. 1985 : Water Quality for Agriculture , Irrigation and Drainage Paper No. 29, Rome
- Gupta, L.C. 1990 : Use of Saline Water in Agriculture - A Study of Arid and Semi-Arid Zones of India , Oxford and IBH, New Delhi
- Kanwar, J.S. 1977 : "Soil Degradation in India", Soil Bulletin, No. 34, F.A.O., Rome
- Kolarkar, A. S. and Singh, N. 1990 : "Runoff Farming in Arid Tract of India : A Review", Indian Journal of Soil Conservation, vol. 18, No. 3, December
- Mamoria, C. B. 1982 : Geography of India , vol. I , Shiva Lal Agarwala, Delhi
- Oesterbaan, R. J. 1983 : "Modern Interferences in Traditional Water Resources in Baluchistan", Water Resources Journal , December
- Sengupta, Nirmal 1991 : Managing Common Property : Irrigation in India and Philippines, Sage Publications, New Delhi
- Sengupta, Nirmal 1993 : User-Friendly Irrigation Designs, Sage Publications, New Delhi
- Singh, N. and Kolarkar, A.S. 1983 : "Some Physico-Chemical Properties of Soils of "Khadins" in Western Rajasthan", Journal of Soil Conservation, vol 11, Nos. 2 and 3
- Stone, Ian 1984 : Canal Irrigation in British India , Cambridge Univ. Press, Cambridge
- Voelcker, J. A. 1893 : Report on the Improvement of Indian Agriculture, London, reprinted Agricole, New Delhi, 1986
- Whitcombe, Elizabeth 1971 : Agrarian Conditions in Northern India, vol I : The United Provinces Under British Rule, 1860-1900 , Univ. of California Press, California

Studies on the changing Tilting Angle of Solar
Array in Rainwater Utilization System

Mitsuo IDE ¹⁾, Kouichi TAKEYAMA ²⁾, Akira HIGUCHI ³⁾,
Kenzo OHARA ³⁾, Hikaru TSUTSUI ⁴⁾

- 1) Irrigation & Drainage DEPT., Tamano Consultants Co., Ltd.,
Hounen-Cho, Chikusa-ku, Nagoya 464 Japan
- 2) Department of Agriculture, Shimane University,
Nishikawatsu-cho, Matsue 690 Japan
- 3) Nikko Kiden Co., Ltd.,
Sakae, Naka-ku, Nagoya 460 Japan
- 4) Department of Agriculture, Kinki University,
Nakamachi, Nara 631 Japan

Abstract

On the earth people get the solar energy at any place, however, it's intensity is as low as 1.4 Kw/m^2 , and it still more decreases by the spectrum absorption in the atmosphere. Thus the higher the latitude the lower the intensity of radiation of solar energy reaching on the earth becomes. Therefore, it may be said that the intensity of solar energy as industrial energy is still weak.

However, unlike other energy sources as fossil fuel and nuclear energy that cause any unbalance of energy on the earth, the solar energy gets new valuable estimations as the local energy by it's impartiality and cleanliness.

So far, this paper studied on the possibility of rain water as a new water resources using photovoltaic solar cells. And here some results for the more effective use of solar energy as a power source were examined, and the more facilitate utilizations of the solar systems were established.

Introduction

Solar Cells used as Drive Source in the Rain Utilization System

We have examined the relationship between installation angle and electromotive force, the gain when a reflecting plate is used, (surface) reflection loss due to incidence angle, and effect of sun follow since 1990. In this paper, we examine the effect of change of angle of the solar arrays, to utilize photovoltaic power generation more effectively.

In addition to the three points to be considered in utilization of solar energy: (1) how solar arrays can be faced directly to the sunlight, (2) how receive area can be increased and (3) how sunlight can be converged, the following three points must also be taken into account, since solar cells are semi-conductor elements.

(1) Solar arrays are so sensitive to the shadow that electromotive force drops drastically even when they are exposed to the shadow of a bird flying in the sky.

(2) The output drops considerably even if a leaf drops on the receive surface of the array.

(3) During measurement of open-circuit voltage, the voltage begins to drop just before midday, since incident light begins to strengthen. This means that electromotive force increases as the sunlight becomes stronger, but the solar array acts as a resistor or insulator if the sunlight is weak. And generated voltage drops if the temperature of solar arrays rises as the temperature is high or incident light becomes stronger.

Therefore, if solar arrays are connected in parallel, reverse current will be produced due to shortage of generated voltage, causing damage to the elements. To protect the elements, bypass diodes or reverse current preventive diodes are required. The latitude of the location of the solar arrays is recommended as the standard angle. This angle is not suitable for summer or winter, and is a result of compromise.

Thus, to make photovoltaic power generation effective in both winter and summer seasons, it is necessary to adjust the angle of the solar arrays according to the seasons.

Method of Experimentation

1. Angle of Solar Arrays

Experiment Location: Kasugai-shi, Aichi Prefecture (north of Nagoya-shi)

Longitude and latitude: Long. 137.0 E

Lat. 35.2 N

Installation of Solar Arrays

Although the automatic sun follow (tracking) method is the best method, the following problems are present in practice.

(1) In addition to the complex biaxial control (east/west and south/north), it is difficult to provide sufficient strength to withstand typhoons.

(2) Solar arrays are normally positioned in parallel in the east-west direction, thus tracking range is limited because one solar array creates its shadow on top of another unless they are sufficiently spaced.

(3) Tracking range is wider in the north/south direction since the solar arrays are sufficiently spaced so that each array is not subjected to the shadow of the previous row. However, tracking angle changes day by day, resulting in completely continuous changes between summer and winter.

(4) Fig. 1 shows estimated power generation for twenty-four seasonal days (old calendar), with the solar arrays placed at the standard angle (35 degrees) and the amount of generated power at the vernal equinox and autumnal equinox considered as 1.00.

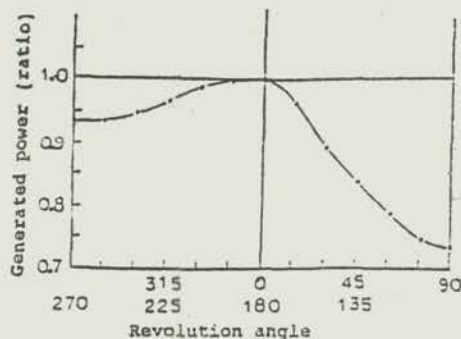


Fig. 1 Revolution Angle of the Earth
and Estimated Generated Power
(When Solar Arrays are Fixed at 35 Degrees.)

(5) Angle of the solar arrays was set to approximately 16 degrees for the summer and approximately 53 degrees for the winter. These angles were obtained by projecting the height of the sun on to the north-south axis when the sun had risen for $\frac{3}{8}$ of the duration of sunshine for the winter solstice and summer solstice, that is the time when the earth has traveled 45 degrees along its orbit from the vernal equinox and autumnal equinox respectively.

Only fine days are taken into account for the above angles, thus it may be necessary to make the angles smaller for collection of diffused light during cloudy or rainy days. In this paper, we examined the validity of this concept by making comparisons with solar arrays which are positioned at the standard angle (35 degrees, inclination 70/100).

Fig. 2 shows estimated changes in electromotive force for each twenty-four seasonal day.

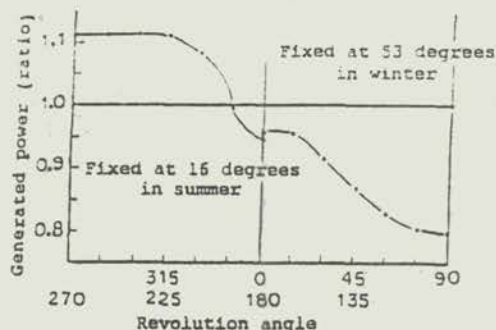


Fig. 2 Revolution Angle of the Earth
and Estimated Generated Power
(When the Angle of Solar Arrays is Changed in 2 Steps)

2. Test Method and Facility

Two sets of solar arrays are used; one is placed at the standard angle (35 degrees, latitude of the installation location) and the other is placed at the following angles, to find out the differences in generated power between the two angle conditions.

Summer (vernal equinox - summer solstice - autumnal equinox):

Approximately 16 degrees

Winter (autumnal equinox - winter solstice - vernal equinox):

Approximately 53 degrees

(1) Measuring facility

In general, solar arrays are used in areas where no commercial power is available, thus the method in which storage batteries are charged directly was introduced instead of the power tracking method as shown in Fig. 3.

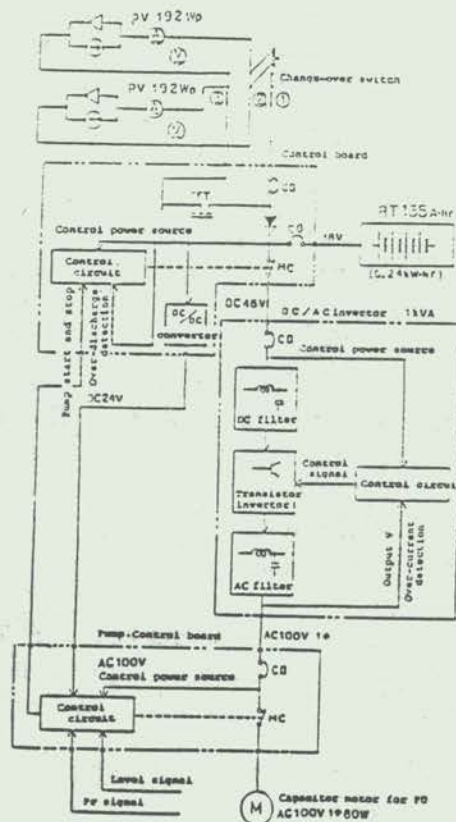


Fig. 3 System Configuration

Specifications of Storage Battery

Nominal voltage: 48 V

Charging voltage: 54 to 60 V

Rated capacity: 130 A hr (20 hours)

(6.24 kW hr)

Since average daily power generation was expected to be approximately 1 kW hr, it was considered that charging voltage (generated voltage) would not fluctuate greatly if the load was appropriate. Thus, a DC/AC inverter (no input load 40 W) was used to exert actual load (i.e. by operating a pump) to obtain equilibrium state.

(2) Measuring method

Measurement was performed on each twenty-four seasonal day or on a fine day around each seasonal day. The measurement items and method are given below.

- * Room temperature: Element temperature was estimated in addition to the open-circuit voltage.
- * Measurement time: Relationship between electromotive force and measurement time (solar time) was checked.
- * Weather: Cloud condition, soft beams of sunlight, cloud etc.
- * Battery voltage: Charged amount was measured.
- * Generated voltage and current: Voltage and current were measured while change-over switch (2) was always connected to switch (1) to supply power.
- * Open-circuit voltage: Voltage was measured while change-over switch (2) was not connected during measurement only.
- * Short-circuit voltage: Current was measured while change-over switch (2) was connected to switch (3) during measurement only.
- * Electric energy: Product of the generated voltage and current was plotted in the section paper at each measuring time, then the number of divisions located below the plotted curve is counted to calculate the electric energy.

(3) Measuring solar arrays

4 sets of solar modules (LA361J48, by KYOCERA) were connected in series to form a single solar array. Characteristics of the solar modules are given below. Fig. 4 shows the output characteristic.

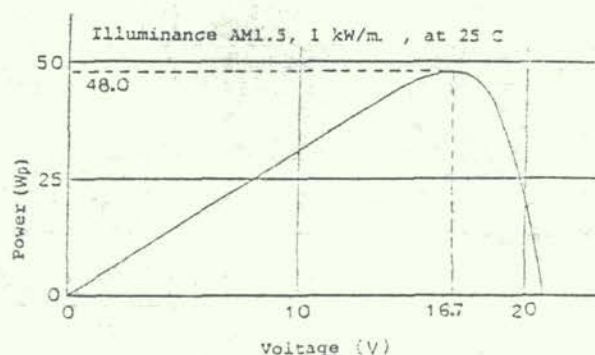


Fig. 4 Characteristics of Solar Module

Maximum output: 48.0 Wp
Optimum voltage: 16.7 V
Optimum current: 2.88 A
Open-circuit voltage: 2.07 V
Short-circuit current: 3.10 A

Measuring conditions:

Intensity of solar radiation: AM1.5, 1 kW/m²

Element temperature: 25°C

(4) Measurement of characteristics of solar arrays

Measurement results will not be reliable if the two sets of solar arrays used as a measuring instrument differ in their characteristics.

The solar modules consist of 36 polycrystalline silicon solar cells which are connected in series, and they differ naturally in their characteristics. It therefore cannot be considered that those two sets of solar arrays used as a measuring instrument show the same characteristics. Thus, comparison test was carried out by placing both sets at the standard angle (35 degrees), to correct the measured data.

The test results and correction method used are shown Table 1.

Table 1 Characteristics of Solar Arrays and Correction

Time	Generated Voltage (same for both arrays)	Battery Voltage (same for both arrays)	Generated Current		Short-circuite Current		Open-circuite Voltage	
			Array A	Array B	Array A	Array B	Array A	Array B
11:45	50.2 V	49.3 V	2.71A	2.71A	2.35A	2.78A	75.8V	74.6
12:00	50.2	49.5	2.68	2.67	2.30	2.73	76.0	75.5
12:15	50.1	49.5	2.60	2.59	2.76	2.70	76.2	75.5
12:30	50.1	49.3	2.48	2.48	2.60	2.53	75.3	75.0
12:45	50.2	49.3	2.61	2.60	2.71	2.64	75.3	75.0
13:00	50.3	49.9	2.50	2.50	2.62	2.55	76.0	75.2
13:15	50.0	49.3	2.40	2.40	2.56	2.50	74.2	74.0
13:30	50.0	49.0	2.40	2.40	2.53	2.49	75.3	74.5

Correction Introduced for Both Solar Arrays

- Correction of current was not carried out since current at operation points was almost identical for both the arrays in the voltage range of between 50 V and 60 V.
- Correction of open-circuit voltage was carried out by deducting 1% from array A in the range of between 70 V and 80 V.
- Short-circuit current fluctuated between 0 A and 3.2 A and seemed inappropriate for the above correction, thus the measured short-circuit current was not used unless required.

(5) Measurement Results

An example of measured data was shown Fig. 5, and measurement results are summarized in Table 2.

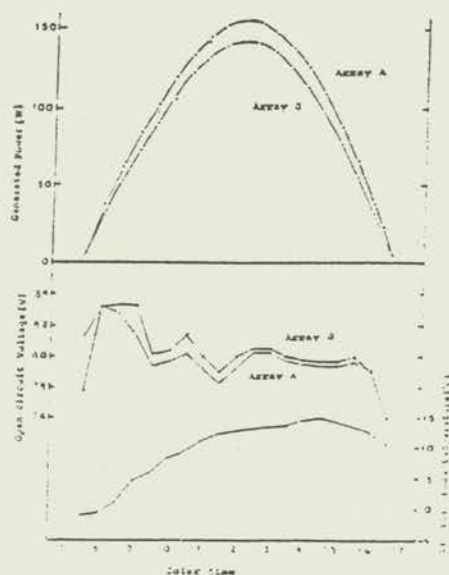


FIG. 5 PERFORMANCE OF A FIXED INCLINATION SOLAR ARRAY

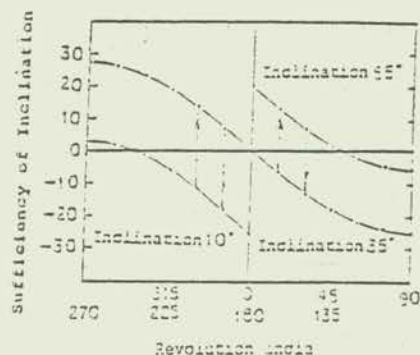


FIG. 6 Sufficiency of Inclination
(Measured at angle of 10° or 55° or possible
duration of sunshine)

Conclusion

(1) We suggest that the solar arrays are placed at 10 degrees (almost horizontally) in summer and at 55 degrees in winter. In this case, we recommend that the angle be changed 4 times in 3 steps (around Aug. 23, Oct. 7, Feb. 18, and Apr. 21, in solar time), instead of being changed twice (summer and winter).

(2) Fig. 6 shows the above relation in terms of sufficiency of inclination of the solar arrays.

If the angle of the solar arrays (designed for 35 degrees) is changed twice (spring and winter), annual amount of generated power can be expected to increase by 6 to 7%.

An increase of 10% or more can be expected if the angle is changed 4 times in 3 steps.

Table 2 Summary of Measurement Results

	Aug. 8	Aug. 23	Sep. 9	Sep. 23	Sep. 25	Oct. 7	Oct. 24	Nov. 8	Nov. 24	Dec. 8	Dec. 22
Sunrise	5° 06'	5° 18'	5° 30'	5° 40'	5° 42'	5° 51'	6° 06'	6° 20'	6° 35'	6° 48'	6° 57'
Sunset	18° 50'	18° 32'	18° 09'	17° 49'	17° 46'	17° 29'	17° 07'	16° 52'	16° 42'	16° 40'	16° 44'
Culmination	11° 58'	11° 55'	11° 50'	11° 45'	11° 44'	11° 40'	11° 36'	11° 36'	11° 38'	11° 44'	11° 50'
Possible duration of sunshine	13 hours and 44 minutes	13.14	12.39	12.09	12.04	11.48	11.01	10.32	10.07	9.52	9.47
Cloudy condition	fine, occasionally cloudy	Fine	Fine	Cloudy in the morning	Fine	←	←	←	←	←	←
Maximum room temperature	42.0°C	37.5°C	36.5°C	32.0°C	28.2°C	29.0°C	24.8°C	22.5°C	16.6°C	17.6°C	15.0°C
Inclination	16°	—	—	16°	53°	—	—	—	—	—	—
Amount of generated power	84.6 Wh	1.038	1.005	63.8	1.022	1.108	1.040	98.5	99.6	93.4	92.7
Amount in the morning	—	—	—	20.1	48.2	55.1	51.4	49.1	49.0	45.6	45.1
Amount in the afternoon	—	—	—	43.7	54.0	55.7	52.6	49.4	50.6	47.8	47.6
Generated current	2.58 A	2.75	2.70	2.59	3.00	3.05	2.84	2.86	3.00	2.76	2.86
Open-circuit voltage	72.8 V	73.5	75.2	75.3	77.1	75.3	77.2	77.1	77.2	78.7	79.2
Amount of generated power	61.6 Wh	78.5	79.4	52.5	84.7	93.9	94.4	93.5	98.4	94.6	96.4
Possible duration of sunshine	35°	—	—	—	—	—	—	—	—	—	—
Inclination	35°	—	—	—	—	—	—	—	—	—	—
Amount of generated power	77.7 Wh	97.3	1.018	58.2	1.013	1.073	99.9	91.7	91.2	84.1	83.4
Amount in the morning	—	—	—	12.0	49.8	53.5	49.5	45.8	45.0	41.1	40.6
Amount in the afternoon	—	—	—	46.2	54.5	53.8	50.4	46.9	46.2	43.0	42.8
Generated current	2.50 A	2.70	2.70	2.71	3.05	3.00	2.78	2.70	2.80	2.50	2.62
Open-circuit voltage	73.5 V	74.0	75.0	75.2	77.2	75.0	77.8	77.3	78.0	79.0	80.0
Amount of generated power	56.6 Wh	73.5	80.5	47.9	86.4	90.9	90.7	87.1	90.1	86.2	86.7
Possible duration of sunshine	1.089	1.067	1.018	(1.096)	0.980	1.033	1.041	1.074	1.092	1.111	1.112
Amount in the morning	—	—	—	(1.675)	0.968	1.030	1.038	1.071	1.088	1.109	1.111
Amount in the afternoon	—	—	—	0.946	0.991	1.035	1.044	1.076	1.096	1.112	1.112
Generated current	1.024	1.091	1.000	0.956	0.984	1.017	1.022	1.069	1.071	1.104	1.092
Open-circuit voltage	0.99	0.99	1.00	1.00	1.00	1.00	0.99	1.00	0.99	1.00	0.99

Building Rainwater Harvesting System to Protect Environment and Develop Production in Helan Mountain

Liu Weinong

(Meteorological Department of Alashan Alliance, Inner Mongolia, Bayanhaote, China, Postal Number: 750300)

Abstract: The precipitation in the mountain area is 210-430 mm, and the maximum of annual precipitation is 672.5 mm. It is an fundamental factor for rainwater harvesting system. The water resources consumed by the inhabitants near the mountain depends on the side-supply of Helan mountain. It is necessary to build rainwater harvesting system, strengthen the green reservoir function of forest, use fast growing trees for a fast forest renewing and widely plant grass in the naked land in forest. Rainwater harvesting system should be built at rock pits, the sites of springs and streams, and the distance between the water supply sites and the animals at the mountain top or foot is about 500 meters. The criterion for judging the function and effect of rainwater harvesting system in the mountainous areas is whether mountain flood takes place after storm occurs in the mountainous areas. **Key words:** Natural and artificial rainwater harvesting system, Rain-fed agriculture

1. General Information

Helan Mountain is more than 200 km long, and more than 20 km wide in average. It runs from nearly north to south. The highest peak of Helan Mountain is about 3556 meters. To the east of this mountain is Yinchuan Plain, and the large Tenggeli Desert is to the west. The climate is arid or severe arid. The precipitation in the mountain area raises along with the increase of altitude. On the contrary, the air temperature decreases as the altitude increases. There are four small climatic blocks which is characteristic by semi-humid, semi-arid, cold, cool or warm etc. The average precipitation of Helan mountain is about 210-430 mm. At the height of 300 m, the maximum of annual precipitation is 627.5 mm. This rainwater resources is very precious in the arid area, and it is the fundamental condition for constructing rainwater harvesting system. The annual average of air temperature is 6.8-1.0 C, which makes the grazing period is up to 60-147 days at the height from 3100 m to 1900 m. From the foot of the mountain to the east edge of Tenggeli Desert, there are many alluvial fans, the soil is thick and fertile, and some fans link into a large area. These fans are suitable for agriculture, husbandry and forestry. In the area, there are the political, economic, cultural center of Alashan Alliance: Bayanhaote, and Barunbieli agricultural area, as well as the Hulus town which is characteristic by coal mining. The water resources, which is used for industry, agriculture and living of human and

domestic animals, is mainly from side-supply of Helan mountain, except for the seepage of rainfall. It is necessary to build mountain rainwater harvesting system so as to protect the ecological system and develop economy of the regions near the mountain areas.

Since 1950's, the precipitation of Alashan Alliance decreased, climate became more arid. There are 20 valleys in the west of this area, the area of the watershed is 612 km², the river water is clear through out the year. In recent years, about 50% of the valleys become dry. The discharge of the largest river Halawu was only 400,000 m³ in 1991, which only accounted for 28.2% of the normal average discharge. In the town Bayanhaote, water supply for human life, industry and agriculture is in great short, and it is also difficult to solve the problem of water supply for the domestic animals around the mountains. The water resources of the Halawu reservoir is often polluted by sheep. Facing the situation of severe water shortage, it is indispensable to exploit the rainwater resources in Helan mountain area, and change the natural harvesting into the combination of natural and man-made harvesting system. It is a systematic engineering, and scientific design and plan is indispensable for a rational and effective use rainwater resources.

2. Strengthening the functions of "Green Reservoir" which is made up of forest and grass land, Optimizing the system of natural rain water harvesting.

From the foot to the top of the mountain, many kinds of plants, such as drought-enduring shrubs, elm, pine, willow, birch, poplar, dragon spruce, and high mountain meadows grow at different altitude. The area of the forest land accounts for about 99.8% of the total mountain area. It consists of thick forest land, sparse woods land, and shrub forest field.

The natural rainwater harvesting of Helan mountain is carried out by a multi-layer plant community: part of rain drops fall down to the leaves of high trees, part of drops fall down to the leaves of lower trees or shrubs across the space between high tree leaves, and the most of the rest drops which directly pass through the above two layers fall down to the grass in the forest. All of the rain drops are broken into pieces by the trunks and leaves, the power of the rain drops are decreased. Therefore, the process of soil erosion is slowed down. It is favorable for soil and water conservation, and protection of eco-system. All of the rain drops which pass through leaves and directly fall down to the ground will also run into the branches and leaves, as well as liver mosses, and the direction of rain water is changed in a mess: some flows in the sideways, some flows even in the direction along mountain ridge. As a result, the distance of rainwater flow is lengthened, and the time for concentration of rainwater flow is extended. It is reported that, in the forest field of Qilian Mountain (near to Helan mountain), the stable infiltration speed is 1.0-33.9 mm per minute, and the speed of seeping

flow is 1.2-29.6 mm per minute. It is very favorable for rain water collecting. In Helan Mountain area, some rainwater is stored in the layer of fallen leaves and dead branch on the ground, some infiltrates into soil or rock crevices or slowly flows into streams, and some of the rainwater flows into the reservoirs out of the mountainous areas or directly flows in Tenggeli Desert.

Affected by the air temperature, precipitation and soil layer, the forest of Helan Mountain grows very slowly. Additionally, at present, only the natural renewing method is applied for forest regeneration. It is unfavorable for rain water harvesting system. Artificial and natural methods should be combined for a speed forest renewing. In different forest, the species of relative fast growing always can be selected out, and the fast growing trees should be chosen for forest renewing. In every year, the seeds of fast growing trees should be collected, and seeds of some fine fast growing trees should be introduced from the areas where the climate and soil are similar to those of Helan Mountain. Then the selected seeds should be planted in sparse forest or the margin of the mountain. In the waste slope land and grassland above the forest, the grass seeds collected from forest land or introduced from near mountains should be planted. Grass land has a more effective function for natural rainwater harvesting than that of forest land.

The mountain rainwater which directly flows into the desert and the rainwater from mountain foot to towns, farms near mountain areas, which flows into desert as surface run off, should be hold back in towns, residential area and the upper reaches of irrigation channels by forest and grass rainwater harvesting systems. It is far more profitable to use the surface or ground water near mountain area by gravitational flow or lifting at the water taking spots than use them by pumping from desert. Furthermore, the water quality is better since the shorter flowing distance.

It would be better planting fast growing trees and grass in the areas discussed above. Moreover, it is necessary to combine the forestry with husbandry.

3. Building the Facilities of Rainwater Harvesting System in Forest Areas.

There is a saying widely popularized in the mountainous areas that "water's height is mountain's height". The warm and wet airflow is lifted by mountain, and it is easy to reach the condensation point. Therefore, precipitation is increased, and it is more in high mountainous area than in low hill areas. The abundant rainfall makes the mountain region be a very good summer grazing area. The kinds of forage grasses are of many grass families, such as alpine wormwood, velvet grass and wheatgrass etc. A hundred mu of grass land can support 17.3 sheep units in grazing season. So, all of the sheep can get fat as long as they can be lead to the mountain. Since 1980's, the climate has become warmer. The grazing period is getting longer. In arid years, there are about 200

herds of sheep coming into the mountainous area. If a herd has 300 sheep, each sheep increase 6 kg, and 1 kg of sheep meat equals to 14 yuan, the profit is 5040,000 yuan a year. If 35 % of them are killed, the profit is 1764000 yuan. The average profit of a herd is 8820 yuan. In recent years, about 50 % of streams are getting dry, and the grass land which lacks of water becomes larger. Sheep are forced to take long distance to drink water. It affects sheep getting fat. So, to build rainwater harvesting system in mountain area is indispensable.

At the height of 2400-2500 meters, rainfall is 290-310 mm, and the grazing period is 98-109 days. Rainwater harvesting system should be built at rock pits, spring opening sites and these places where rainwater flow is stored or collected. Below this height, there is conifers tree, forest, and mixed forest, while above this height is dragon spruce forest. Both the two forest belts are the main distribution area of edder, musk deer, blue sheep. The distance between the water supply sites and the animals at the mountain top or foot is about 500 meters.

The criterion for judging the function and effect of rainwater harvesting system in the mountainous areas is whether mountain flood takes place after storm occurs in the mountainous areas. After storm, if mountain flood does not occurs, it indicates that the function of rainwater harvesting system in the mountainous areas is good and effective. It is the target for us which we will reach in future after much hard work and efforts for a few years.

4. Making a good use of proverbs and rehabilitating rain-fed agriculture

In 50's rain-fed agriculture was widely spread out in the mountainous areas. Buckwheat and gruel crops were planted just before or after heavy rain, and generally, a good yield was obtained. After that time, irrigation agriculture has been developed rapidly by the effort of local government, while rain-fed agriculture has been abandoned gradually. At present, due to the rational price of forages, it is profitable to rehabilitate rain-fed agriculture, which is at a low cost, and plant gruel crops in the mountainous areas. Additionally, much waste land field and rotation-farmed land can be used.

The peasants near the mountain area are very familiar with the relationship between cloud and rainfall. A lot of proverbs, such as " South-Easter blows, rain comes soon" etc, are popularized widely in the mountainous region. When Helan Mountain is covered with clouds, it shows that the vapor in the low level is very abundant, and the height for vapor to condense into cloud is about 1100-2000 meters. In the meantime, south-easter blows and the warm and wet airflow is lifted by the mountain slope. So, vapor is condensed and rain is formed. Based on much observing records, the author of this paper made a research on the relationship between the cloud and rain in the mountain area in 1983. During the period in which cloud was formed for 106 times, rain occurred correspondingly

for 77 time. The probability reaches 73%. For those peasants and herdsmen, who can not obtain the information of weather forecast, these proverbs are very useful, and also of great value in farming practice for them to forecast rain and arrange their rain-fed agriculture. Agricultural and meteorological departments should widely spread out the popular sciences and technology among the massed.

Reference Books

- [1] Fu Huien, 1991, Research on the relationship between climate and water resources in the forest of Qilian Mountain. Beijing, Chinese Science and Technology Press " Natural Symposium on Climate Change and Environment" page 127.
- [2] Liu Weinog, 1991, Climate resources division of Alashanzuoqi, page 229, Huhehaote, Inner Mongolia people's press.

Relationship among Acid Precipitation and Meteorological Factors

Wang Xirong Zheng Deqing Wang Hongxing
(Associate prof.) (Lecturer)
(Heilongjiang Hydraulic Engineering College)
No. 209 Xuefu Road Harbin Postal Code: 150086

1 Introduction

Heilongjiang Province lies in the northeast part of China, covers an area of 453,900 km², 4.7% of total land area, and is rich in large supplies of natural resources, such as crude oil, crop, coal and timber.

Due to economic development, natural resources exploitation and growth of population, natural environment deteriorate gradually and lead to acid precipitation.

As a global problem, acid precipitation are deeply concerned.

Acid precipitation can cause soil acidification, loss of soil nutrition, and seriously affect the activity of microorganism in soil and the normal growth of crop and yield.

In this paper, the causes of forming acid precipitation, composition and its relationship with meteorological factors are discussed.

2 Relationship between acid precipitation and ion concentration

Table 1 and Table 2 are statistics tables of ions in acid precipitation of 1991 and 1992. According to these statistics, SO_4^{2-} is the main composition, its annual maximum is 79.44 mg/t in 1991, 112.9 mg/t in 1992. NO_3^- takes second place in composition. SO_4^{2-} is about 54% of total ions and NO_3^- is about 29%.

Table 1 Statistics of Ions in 1991 (mg/T)

Statistics data	item	K ⁺	Na ⁺	Ca ⁺⁺	Mg ⁺⁺	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ⁻²
Number of examples		24	24	24	24	24	24	24	24
Minimum		0.102	0.069	0.003	0.002	0.014	0.020	0.320	0.050
Maximum		4.09	13.25	24.25	1.60	0.36	10.40	10.92	79.44
Average		0.317	0.123	2.123	0.127	0.276	1.100	2.441	4.357

Table 2 Statistics of Ions in 1992 (mg/T)

Statistics data	item	K ⁺	Na ⁺	Ca ⁺⁺	Mg ⁺⁺	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ⁻²
Number of examples		35	35	35	35	35	35	35	35
Minimum		0.043	0.042	0.033	0.021	0.037	0.035	0.112	1.890
Maximum		6.480	10.800	37.900	4.510	2.240	5.110	11.200	112.900
Average		0.595	0.729	4.740	0.331	0.651	0.982	3.025	25.271

Many factors related to the chemical composition of precipitation, such as locality, season, attribute of air mass, type of cloud, rainfall character, precipitation and local pollution source.

There are three types of materials causing acid precipitation:

- (1) Sulphide and its radical: (SO_2) , (SO_3) , (H_2S) , $[(CH_3)_2S]$, (H_2SO_4) , (CH_3SH) .
- (2) Chemical compound and radical of nitrogen: (N_2O) , (NO) , (NO_2) , (NO_2^-) , (NO_3^-) , (HNO_3) , (NH_4^+) , (H_2) .
- (3) Chloride and its radical: (Cl^-) , HCl .

Among all these materials causing acid precipitation, H_2SO_4 and HNO_3 are the main causes and direct derivate of SO_x and NO_x .

3 Comparision of acid rainfall frequency in typical station

Three station, Wuchang, Nenjiang, Jiamusi, are adopt for comparision of acid rainfall frequency. No pollution sources are found in Wuchang Station.

Table 3 and Fig.1 show frequency of acid rainfall in Wuchang is 37.9% of the total, 9.8% in Jiamusi, 29% in Nenjiang.

Table 3 Frequency of Acid Rainfall in 1993

Month	1	2	3	4	5	6	7	8	9	10	11	12
Station												
Wuchang	100	50	0	0	14	14	27	67	73	56	29	20
Jiamusi	0	0	0	0	0	33	12	7	25	40	0	0
Nenjiang	25	0	100	25	0	13	33	6	11	0	25	100

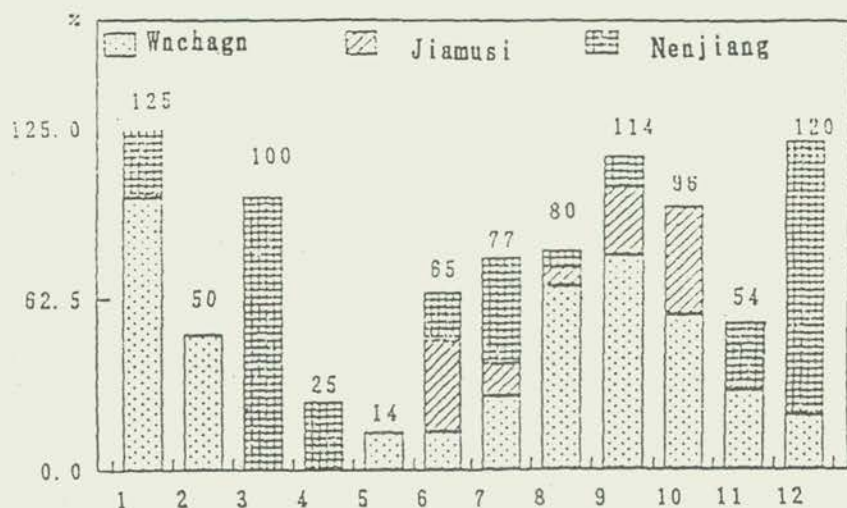


Fig.1 Frequency of Acid Rainfall in 1993

Table 4 and Fig. 2 show frequency of acid rainfall in Wuchang from 1992 to May of 1994. The annual average frequency is 42.5% in 1992, 37.9% in 1993, and 28.3% in 1994. Average frequency drops every year.

Table 4 Frequency of Acid Rainfall in Wuchang

M	1	2	3	4	5	6	7	8	9	10	11	12
Y												
1992	50	20	25	32	76	17	23	17	43	75	50	38
1993	100	50	0	0	14	14	27	67	73	56	29	20
1994		100	0	0	12							

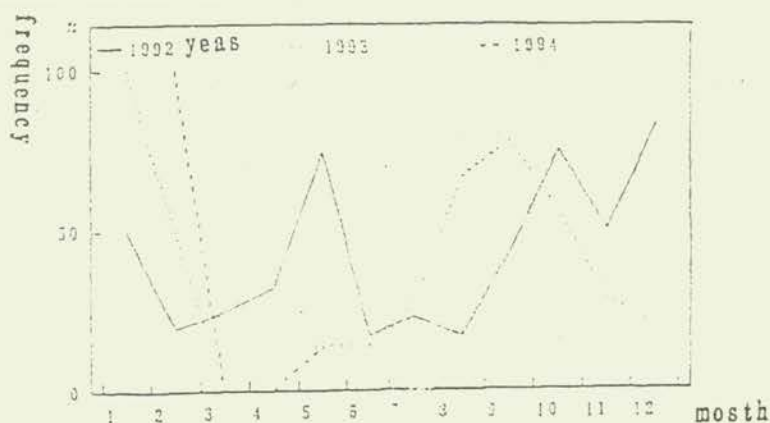


Fig. 2 Frequency of Acid Rainfall in Wuchang

4 Relationship among acid precipitation and meteorological factors

4.1 Relationship among acid precipitation and wind direction

Table 5 shows the occurrence time of different wind direction.

Table 5 Statistice of Wind. times and disection in Wuchang Station when Acid Rainfall Occer

Disection	E	SE	S	SW	W	NW	N	Total
Occur Times	0	16	6	28	2	9	2	6
Percentage of Total Time	0	25	9	43	3	14	3	100

When acid precipitation occurs in Wuchang Station, SW wind 28 times, 43% of the total sum. SE wind 16 times, 25% of the total sum.

4.2 Relationship between acid precipitation and rainfall

Table 6 Monthly Average of Rainfall in Wuchang Station

Rainfall Y	M											
	1	2	3	4	5	6	7	8	9	10	11	12
1992	1.70	2.40	5.05	6.10	3.60	3.60	14.56	6.55	10.30	7.70	4.60	1.55
1993	1.30	2.13		3.57	11.6	11.6	7.98	7.33	8.98	9.51	3.43	3.26
1994		2.0	2.50	6.05	5.55							

Table 6 shows average precipitation from 1992 to May of 1994 in Wuchang Station.

Acid precipitation occurs 65 times. There are 39 times when acid precipitation is more than rainfall, and 21 times acid precipitation less than rainfall.

4.3 Relationship among acid precipitation and meteorological factors

Tables 7 shows the meteorological background when acid precipitation occurs.

Table 7 Meteorological Background in Wuchang Station when Acid Rainfall occurs

Weather conditions	AS.	Cb.	AS	Sc	Nn	=
Occurrence Time	25	14	12	8	6	39
Percentage of Total Sum	38	22	18	12	9	60

When acid precipitation occurs, high cloud and fog exist in the same time 25 times, 38% of total sum. Rain cloud and fog exist 14 times, 22% of total sum. Only high cloud exist 12 times, 18% of total.

Only anvil cloud exist 8 times, 12% of total. Only rain cloud 6 times, 9% of total.

When acid precipitation occurs, 60% is accompanied by fog.

5 Comments

Four different stations in Heilongjiang have different acid rain

frequency. Some station lie in developed area, some station lie in undeveloped area. But only partial correlation exist between acid precipitation and industrial development. That means part of acid precipitation are intrusive precipitation.

IMPACT OF ENVIRONMENTAL CHANGES ON RAINFALL PATTERN AND ARIDITY IN EASTERN-SUDAN

Dr. Shamsul Haque Alvi, Associate Professor

and

Nadir Ahmed Elagib, M. Sc. Student

Department of Civil and Architectural Engineering,

University of Bahrain, P. O. Box 32038,

Bahrain

ABSTRACT

The paper is confined to the study of the changing rainfall pattern and the assessment of aridity situation in Eastern-Sudan which is brought about by harsh environmental changes, particularly the temperature. Adequate monthly and annual rainfall data observed for three meteorological stations, viz. Port Sudan, Kassala and El Gedaref, are analysed, using various statistical techniques, to highlight all aspects of rainfall in the region. Based on all available relevant data, particularly rainfall data which are most fundamental, the evaluation of the degree of aridity of the areas under consideration is achieved by three aridity indices proposed by number of investigators. The findings clearly point out a real decay of natural ecosystem of Eastern-Sudan as a result of protracted drought.

INTRODUCTION

Hyper-arid, arid and semi-arid lands constitute about 30 per cent of the world's land surface [1]. Recently, as a result of increasing awareness of the environmental problems, considerable attention is being paid to such areas. Of these problems, drought and desertification are the most important ones. Drought is defined as a temporary condition of severe and prolonged deficiency of water to meet requirement (rainfall is often used as the best single index of drought) [2]. Desertification, on the other hand, is defined as a process of expansion or intensification of desert [2]. It occurs when drought becomes permanent [3].

Desertification in Sudan has become more serious now. Out of about 2.5 million square kilometres, the total area of Sudan, about 29 per cent is desert and about 26 per cent is prone to desertification [4]. The characteristic rainfall insufficiency of desertic regions has been noticed in many areas in the country during the past few decades, which is very adversely affecting agricultural schemes and resulting in tragic famines. The eastern region (Fig. 1) is part of the country which is drastically influenced by the frequent droughts.

Three index meteorological stations, namely Port Sudan (19° 35' N 37° 13' E), Kassala (15° 28' N 36° 24' E) and El Gedaref (14° 02' N 35° 24' E), are taken in the present study for the appraisal of the impact of environmental changes on rainfall pattern and

its consequent role in enhancing the vulnerability of the region to desertification. The length of rainfall records obtained for the study is 52 years stretching from 1941 to 1992.

ENVIRONMENTAL CHANGES

Climatic anomalies and human activities have the potential to lengthen aridity phases, raise air temperature and intensify erosive winds [5]. At global level, it is well known that the warmth or rise in temperature will have a great impact on rainfall patterns - an increase in rainfall in some parts of the world and a decrease in other parts.

The recent trends of temperature anomalies in the eastern region of Sudan have been investigated by computing the deviations of mean annual temperatures from the long term mean (LTM) since 1941 as illustrated in Figs. 2 to 4. As can be seen, higher temperatures are noticeable in the region, especially during the recent 30 years. By performing linear regression, this increase in the mean annual temperature since 1941 has been estimated to occur at a significant rate of 0.012 to 0.028°C per year. On a monthly basis, the deviation from the mean can be observed more clearly. For instance, in the drought year of 1984, as illustrated for Kassala (Fig. 5), the increase in temperature in the region was enormous and reached to as much as 3.6°C. Consequently, the mean annual temperature in Kassala increased by 1.3°C over the long term mean. On the other hand, many human factors can probably be responsible for desert propagation, some of which are overgrazing, overcropping, forest fires and deforestation [5].

MONTHLY RAINFALL

General Characteristics

Figs. 6 through 8 compare the monthly long term mean and 1984 rainfalls. The year 1984 is chosen as indicative year for the impact of environmental change on rainfall behaviour, when a severe drought struck Sudan as were many other parts of Africa. The long term mean monthly rainfall patterns reveal that the wettest month of the year is November for Port Sudan and August for Kassala and El Gedaref, having average rainfalls of 42.8, 96.8 and 181.7 mm respectively. In 1984, the wettest months for the three locations were October for Port Sudan and July for Kassala and El Gedaref. The comparison clearly exhibits the erratic behaviour of rainfall of this year. While heavier rains were received in some of the months in Port Sudan, lighter monthly rains were registered in the other two stations.

Distribution over the Year

The distribution of rainfall over the year can be observed better by expressing the mean monthly rainfall as percentage of the mean annual rainfall as shown in Figs. 9 to 11. The irregularity of rainfall throughout the year in Port Sudan is quite obvious. About 90 per cent of the annual rainfall occurs during the period June-September for both Kassala and El Gedaref and during July-January for Port Sudan. On an average, 47.4, 34.0 and 30.9 per cent of the total annual rainfall amounts occur in the rainiest months in Port Sudan, Kassala and El Gedaref respectively.

RAINY SEASON

Gausson [6] defined the dry month as the month for which the mean rainfall, measured in mm, is less or equal to twice the mean temperature, measured in °C. That is

$$P \leq 2t \quad (1)$$

It follows that if $P > 2t$, i.e. $P/t > 2$, then the month is considered wet. This approach is used herein to recognize the rainy season of the year as shown in Table 1. Hence, the span of rainy season in months in Port Sudan, Kassala and El Gedaref are 0, 2 (July-August) and 4 (June-September) respectively. In the particular drought year of 1984, the corresponding spans of rainy season were considerably shortened in Kassala and El Gedaref to 0 and 2 months (July and September) respectively.

Table 1 Dry and Wet Months of the Year

Month	Port Sudan		Kassala		El Gedaref	
	P/t		P/t		P/t	
	1941-92	1984	1941-92	1984	1941-92	1984
Jan	0.2	0.0	0.0	0.0	0.0	0.0
Feb	0.0	0.0	0.0	0.0	0.0	0.0
Mar	0.0	0.0	1.0	0.0	0.0	0.0
Apr	0.1	0.0	0.1	0.0	0.1	0.0
May	0.1	0.0	0.3	0.0	0.8	0.5
Jun	0.1	0.0	0.8	0.3	2.7	1.0
Jul	0.2	0.0	2.9	1.7	6.2	4.7
Aug	0.1	0.0	3.4	0.1	6.9	1.9
Sep	0.0	0.0	1.6	0.9	3.4	2.6
Oct	0.4	1.8	0.3	0.0	0.9	0.2
Nov	1.6	0.2	0.1	0.0	0.1	0.0
Dec	0.7	0.9	0.0	0.0	0.0	0.0

Note: $P/t > 2$ indicates a wet month, otherwise a dry month

EXTREMES

Referring to Figs. 12 to 14, which give the maximum rainfall recorded both in one day (1951-90) and in one month (1941-92), it can be seen that the highest rainfalls ever recorded in one day in Port Sudan, Kassala and El Gedaref are 111.5 mm (November), 104.5 mm (June) and 113.6 mm (July) respectively and likewise the highest rainfalls recorded in one month are 182.0 mm in November, 274.5 mm in July and 449.4 mm in August respectively.

ANNUAL RAINFALL

General Characteristics

It is quite obvious from Figs. 15 to 17, which present both the time series of annual rainfall and the progressive 5-year moving average, that the tendency of rainfall to fluctuate from year to year is the most dominant characteristic. To make clear quantitative observations

about the rainfall behaviour in the three regions, statistical measures have been applied and presented in Table 2. The largest amount of rain is received in El Gedaref whereas the lowest is received in Port Sudan. Correspondingly, the variation reflected by the coefficient of variation (C_v) decreases with increasing rainfall. By looking at the mean (μ) values of the three indicated periods, it becomes evident that the mean has appreciably reduced indicating a gradual drop in the last five decades. This reduction in the quantity of rain is also detected by performing linear regression and studying 5-year moving averages. Both techniques show falling trends of the series from the 1940s to the early 1990s. Quantitatively, the slope of the best linear fit or the trend rate (TR) observed for Port Sudan, Kassala and El Gedaref show a decrease in rainfall at a rate of 1.558, 2.820 and 0.142 mm per year respectively.

Table 2 Statistical Analysis of Annual Rainfall

Station	1941-92				1963-92				1980-90
	μ (mm)	σ (mm)	C_v (%)	TR (mm/Yr)	μ (mm)	σ (mm)	C_v (%)	TR (mm/Yr)	μ (mm)
Port Sudan	89.8	61.4	68.4	-1.558	70.7	47.3	66.9	-1.174	49.8
Kassala	283.8	91.4	32.2	-2.820	247.3	85.7	34.7	-2.029	221.4
El Gedaref	586.4	105.4	18.0	-0.142	592.5	111.3	18.8	-2.596	570.6

Interesting relationships have been obtained with very high correlation factors (r). The standard deviation (σ) is found to increase with the mean as:

$$\sigma = 11.337 \mu^{0.3594} \quad r = 0.977 \quad (2)$$

and the coefficient of variation is found to correlate also with the mean as:

$$C_v = 1131.6 \mu^{-0.6402} \quad r = -0.993 \quad (3)$$

Eqs. (2) and (3) are graphically presented in Figs. 18 and 19 respectively.

Dry and Wet Spells

As shown in Figs. 15 through 17, the eastern region of Sudan has experienced rainfall anomalies (very high or very low rains). The highest annual rainfall recorded in Port Sudan, Kassala and El Gedaref were 266.1, 464.0 and 864.1 mm respectively. In El Gedaref, below average rainfalls were recorded mostly in the first 30-year period of data. This explains the decrease in the long term mean over the normal rainfall. In Port Sudan and Kassala, however, the pattern is reversed: they experienced most below average rainfalls during the latest 30-year period. During the 52-year data period, 31, 27 and 26 years were drier than the average of the period for Port Sudan, Kassala and El Gedaref respectively. The anomalies are more pronounced in the three stations within the period 1980-90. In Table 3, the most significant dry and wet spells of this period are spelled out. The driest years among the period considered in the present study, i.e. 1941-92, were 1983 for Port Sudan, 1990 for Kassala and 1984 for El Gedaref. In these years, the annual rainfalls diminished to about 0, 27 and 54 per cent of the long term means respectively. The table shows that there is only one rainfall, recorded for Kassala in 1988, which is above long term average by about 39 per cent.

Table 3 Significant Dry and Wet Spells of the Period 1980-90

Station	1983 (mm)	1984 (mm)	1988 (mm)	1990 (mm)
Port Sudan	0.0	83.0	13.9	49.5
Kassala	249.4	98.8	393.8	75.6
El Gedaref	504.1	319.0	584.0	371.9

Classification

It is of interest to classify the departure of values in the rainfall series from the mean. Conrad [7] gives classification of any climatic element by expressing the departure as number of standard deviations. Accordingly, the annual rainfall records fall within sub-normal to greatly above-normal class for Port Sudan, within sub-normal to extremely above-normal class for Kassala and within the class of greatly sub-normal to greatly above-normal for El Gedaref.

Frequency Distribution

The entire 52-year annual rainfall data for the three stations are displayed in frequency distribution histograms as shown in Figs. 20 to 22. The rainfall groupings (classes) used to form these graphs are 15, 25 and 30 mm respectively. It can be seen from the figures that the modal rainfall class (MC) tends to shift towards the middle of the range as mean annual rainfall increases. The percentage of this modal class (PMC) or the relative frequency of it increases with increasing mean annual rainfall. The estimated modal rainfall amount (M) in mm (the most frequent in the distribution) is observed to correlate with the mean by the relationship:

$$M = -73.883 + 1.127 \mu \quad r = 0.992 \quad (4)$$

which is presented in Fig. 23.

Probability

Assuming that annual rainfall records for the regions under consideration are normally distributed, the probable rainfall quantities with 1.25, 10 and 50-year return periods associated with 80, 10 and 2 per cent probabilities respectively, have been estimated and the respective relationships obtained between these expected rainfall amounts (RF) and the mean are represented by Eqs. (5), (6) and (7) and further illustrated in Fig. 24. 80 per cent probability is usually taken as suitable for planning purposes in Sudan [8].

$$RF = -49.434 + 0.929 \mu \quad r = 0.997 \quad (5)$$

$$RF = 75.405 + 1.109 \mu \quad r = 0.999 \quad (6)$$

$$RF = 120.772 + 1.174 \mu \quad r = 0.999 \quad (7)$$

ARIDITY

Hostile climatic episodes of severe magnitudes have become common features in Sudan, causing a serious degradation of land. It is worthwhile to measure the degree of encroachment and intensification of desert in the eastern region of Sudan. Three comparative aridity indices are adopted to facilitate the task of locating the study areas within the appropriate climatic zone. These indices are:

- Budyko-Lettau dryness ratio ,D, [1] which indicates the number of times the net energy income of the surface could evaporate the annual precipitation.

<u>D</u>	<u>Aridity Zone</u>
> 3.4	Desert
2.3-3.4	Semi-desert

- P/PET ratio by UNEP [5], which expresses precipitation as a fraction of the potential evapotranspiration.

<u>P/PET</u>	<u>Aridity Zone</u>
< 0.05	Hyper-arid
0.05-0.2	Arid
0.2-0.5	Semi-arid

- Lang's aridity index ,A_L, [6] which is the fraction of annual precipitation to mean annual temperature.

<u>A_L</u>	<u>Aridity Zone</u>
0-20	Arid
20-40	Semi-arid

Using the necessary climatic data for the period 1963 to 92 (normals) and the difficult drought year of 1984, the above mentioned aridity indices have been calculated for the three stations and the classification accorded are tabulated (Table 4). This table emphasizes the extreme state of distress by aridification process in the region. The vulnerability to the process varies from semi-arid (El Gedaref) to hyper-arid (Port Sudan). The 1984 drought had enormously affected the region of eastern Sudan especially Kassala and El Gedaref.

Table 4 Evaluation of the Degree of Aridity in the Study Regions by Aridity Indices

Station	1963-92			1984		
	D	P/PET	AL	D	P/PET	AL
Port Sudan	Desert	Hyper-arid	Arid	Desert	Hyper-arid	Arid
Kassala	"	Arid	"	"	"	"
El Gedaref	Semi-desert	Semi-arid	Semi-arid	"	"	"

It is interesting to see the graphical display of the calculated indices against precipitation as given in Figs. 25 through 27. In regression forms, the various relationships developed as a result of the analysis made in this study are given as follows:

$$D = 1.837 + 9533.4 P^{-1.359} \quad r = -0.996 \quad (8)$$

$$P/PET = -0.0094 + 4.224 \times 10^{-4} P \quad r = 0.994 \quad (9)$$

$$A_L = -0.0964 + 0.0345 P \quad r = 1.000 \quad (10)$$

Eqs. (8) through (10) are very easy and useful in estimating aridity indices since they avoid the complications involved in the traditional methods of calculation where many factors other than precipitation are taken into consideration.

CONCLUSIONS

In the light of the detailed study of the rainfall pattern and evaluation of the extent of aridification process in Eastern-Sudan, the following conclusions can be drawn:

- (1) The progressive alteration of natural environment of the region has been perceived by rising trends of mean annual temperatures, at rates ranging between 0.012°C and 0.028°C per year for the index stations considered, and by consequent recurrent droughts as well as land degradation.
- (2) The prolonged rainfall desiccation or failure of expected rainfall has declined at rates of 0.142 to 2.820 mm per year.
- (3) The period extending from 1980-90 was the most stressful period for the region in the recent history, among which the worst known drought was that of 1984.
- (4) Many principal formulae related to the varying rainfall resource and degree of aridity in the region have been established. The amount of rainfall expected with 80% probability (suitable for planning purposes in Sudan) can be estimated from the mean annual rainfall by the equation:

$$RF = -49.434 + 0.929 \mu \quad r = 0.997 \quad (5)$$

To avoid the complications associated with cumbersome methods of estimating Budyko-Lettau dryness ratio, P/PET ratio by UNEP and Lang's aridity index which are used to assess aridity of a region, the following equations are proposed to estimate the respective aridity indices from annual precipitation:

$$D = 1.837 + 9533.4 P^{-1.359} \quad r = -0.996 \quad (8)$$

$$P/PET = -0.0094 + 4.224 \times 10^{-4} P \quad r = 0.994 \quad (9)$$

$$A_L = -0.0964 + 0.0345 P \quad r = 1.000 \quad (10)$$

REFERENCES

- [1] "Desertification: Its Causes and Consequences", Compiled and Edited by the Secretariat of the UN Conference on Desertification, Nairobi, Kenya, 29 August to 9 September, 1977, UNEP, Pergamon Press, p.7, 71.
- [2] Perry, A. H., "Precipitation and Climatic Change in Central Sudan", Rural Development in White Nile Province, Sudan, a Study of Interaction between Man and National Resources, Edited by Davies, H. R., The United Nations University, 1986, p. 38, 39.
- [3] Elagib, A. A., "New Technology May Enable Man to Increase Water Resources and Reverse Desertification", Proceedings of the International Conference on Water Resources Needs and Planning in Drought Prone Areas, Part 1, Sudan Engineering Society and UNESCO Publication, Khartoum, Sudan, 6th-12th December 1986, p. 621-628.
- [4] ALECSO, "Green Belt Project in North Africa - Combat of Desertification Northern African Countries" (in Arabic), March 1987, p. 21.
- [5] Hare, F. K., "Climate Variation, Drought and Desertification", WMO-No. 653, 1993, p. 5.
- [6] Kamil, M. W., "Climate and Meteorology" (in Arabic), University of Halab Publication, Syria, 1983, p. 264, 266.
- [7] Landsberg, H., "Physical Climatology", 2nd Ed., 1958, p. 73.
- [8] Salih, A. M. et al, "Water Resources in Sudan", National Council for Research, 1st Ed., Khartoum, Sudan, 1982, p. 16.

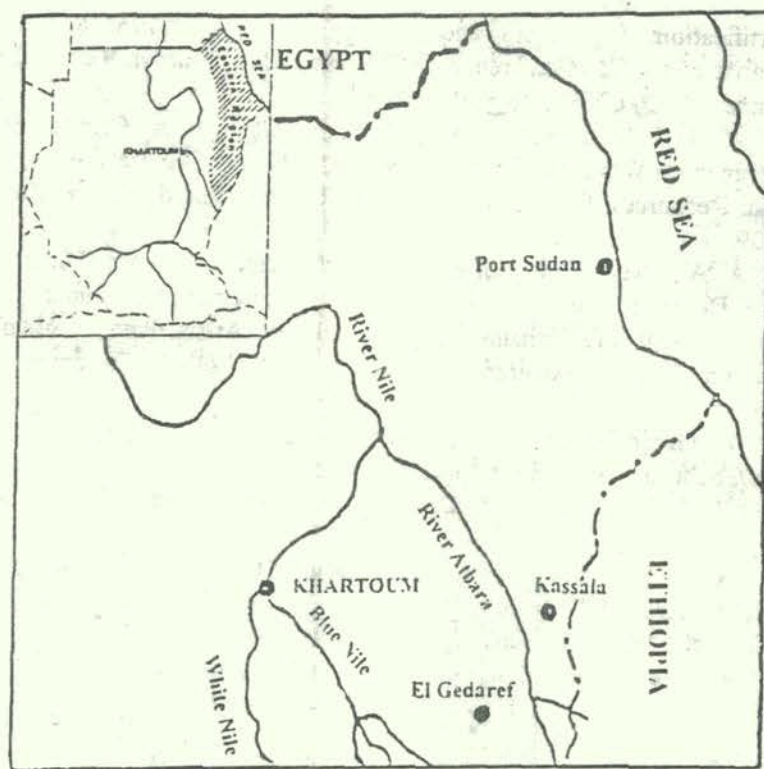


Fig. 1 Eastern Region of Sudan

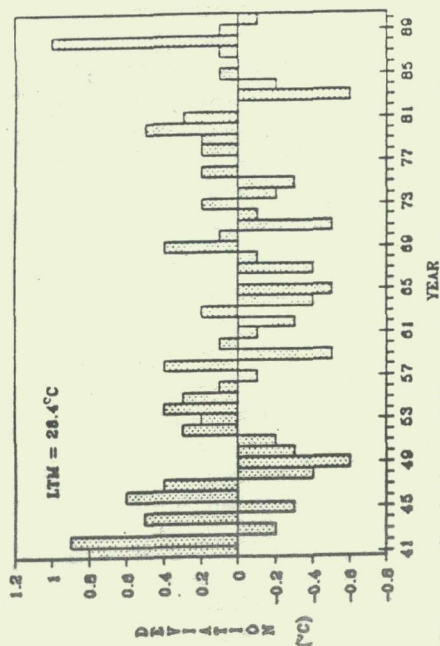


Fig. 2 Deviation of Mean Annual Temperature from Long Term Mean (Port Sudan)

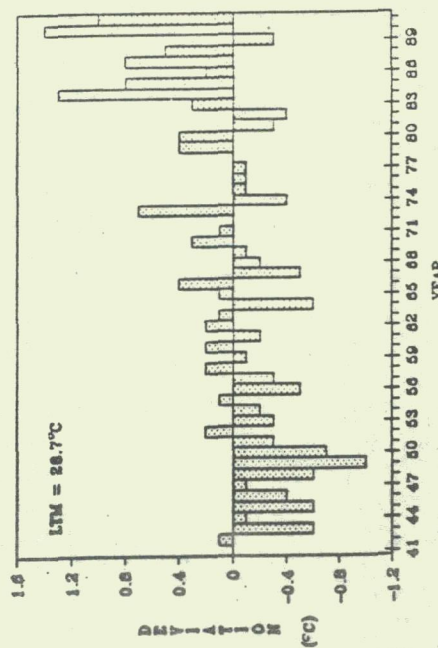


Fig. 4 Deviation of Mean Annual Temperature from Long Term Mean (El Gedaref)

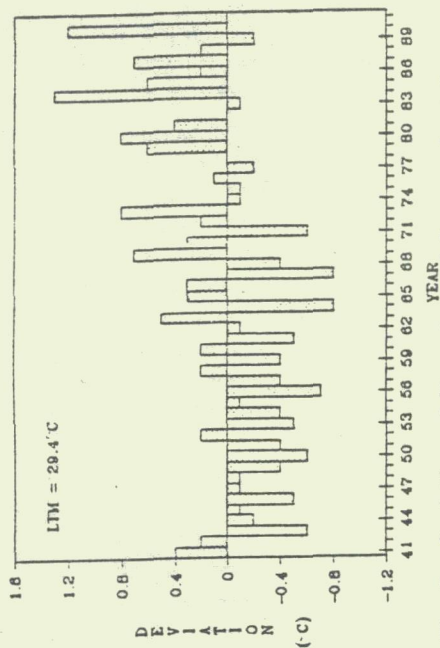


Fig. 3 Deviation of Mean Annual Temperature from Long Term Mean (Kassala)

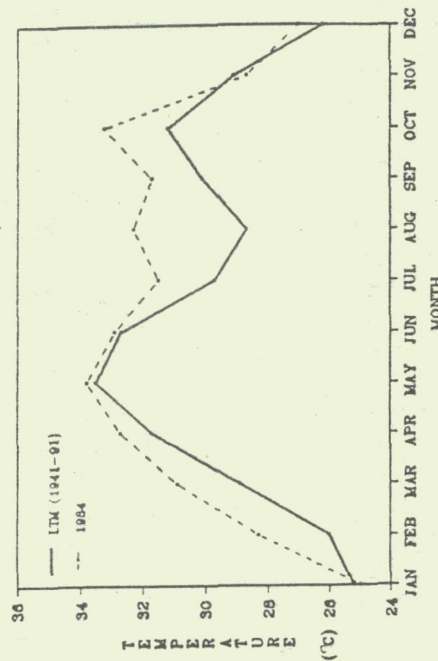


Fig. 5 Mean Monthly Long Term and 1984 Temperatures (Kassala)

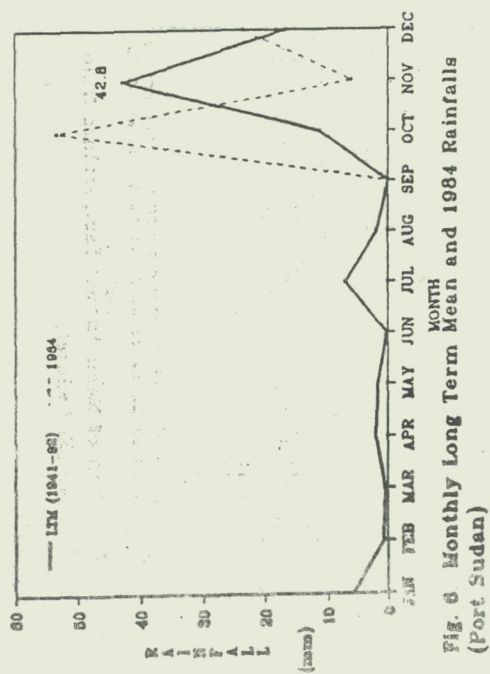


Fig. 8 Monthly Long Term Mean and 1984 Rainfalls (Port Sudan)

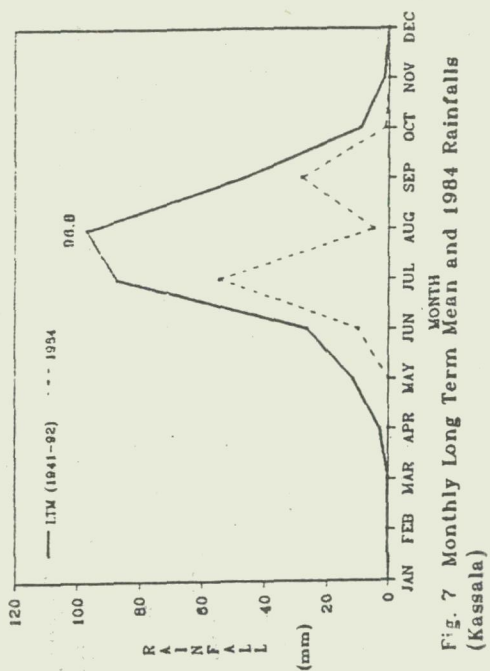


Fig. 7 Monthly Long Term Mean and 1984 Rainfalls (Kassala)

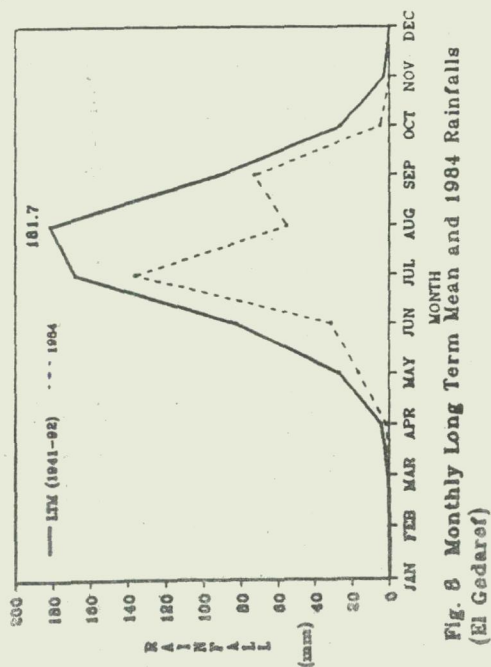


Fig. 8 Monthly Long Term Mean and 1984 Rainfalls (El Gedaref)

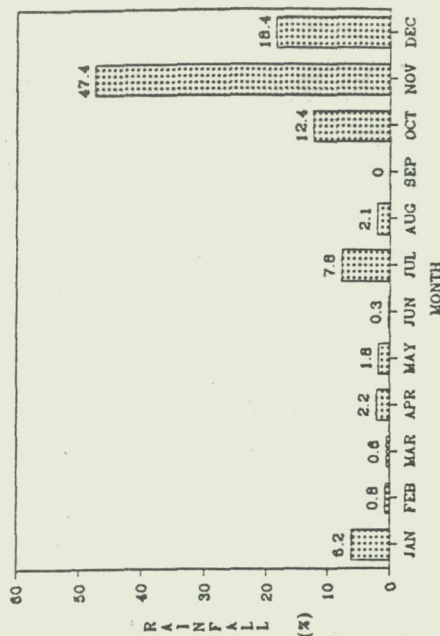


Fig. 9 Mean Monthly Rainfall as Percentage of the Mean Annual (Port Sudan 1941-92)

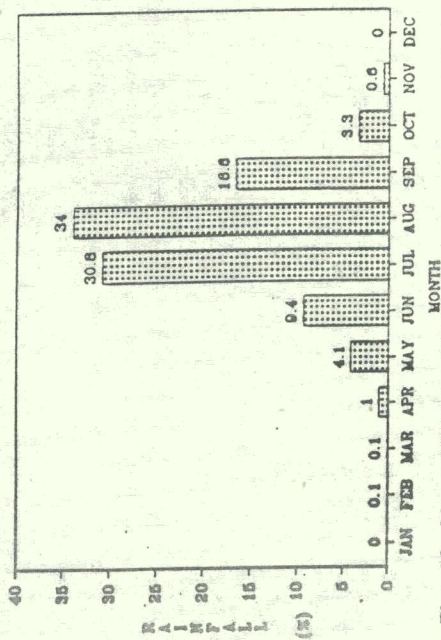


Fig. 10 Mean Monthly Rainfall as Percentage of the Mean Annual (Kassala 1941-92)

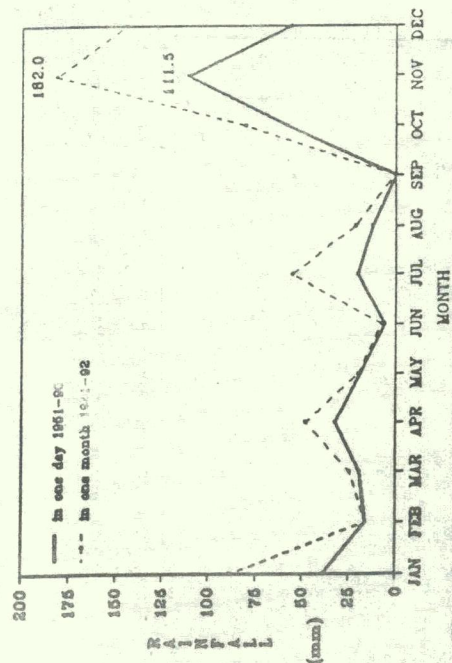


Fig. 12 Maximum Rainfall Recorded in One Day and in One Month (Port Sudan)

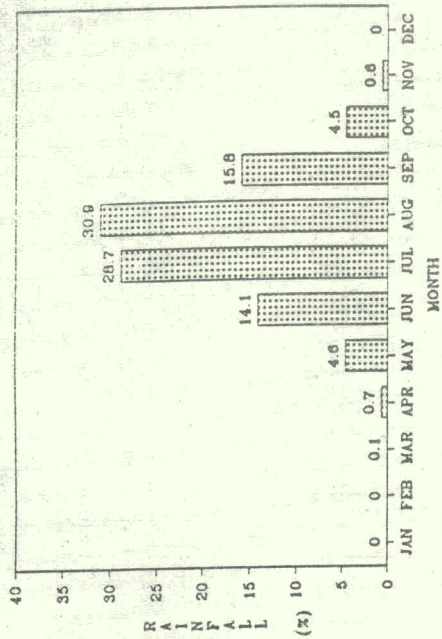


Fig. 11 Mean Monthly Rainfall as Percentage of the Mean Annual (El Gedaref 1941-92)

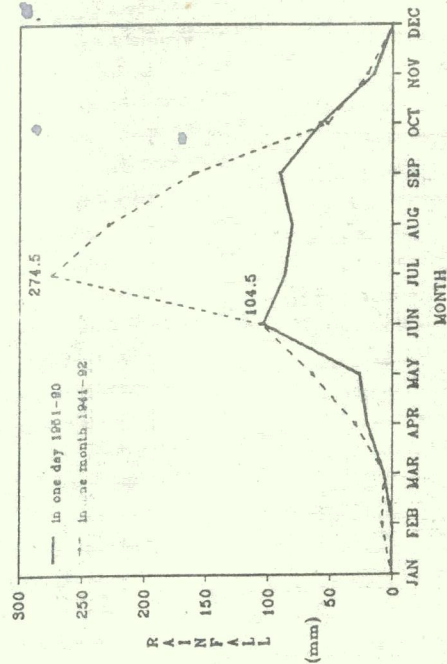


Fig. 13 Maximum Rainfall Recorded in One Day and in One Month (Kassala)

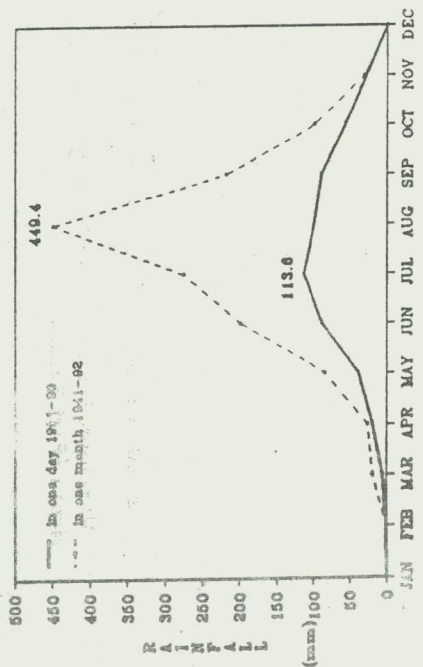


Fig. 14 Maximum Rainfall Recorded in One Day and in One Month (El Gedaref)

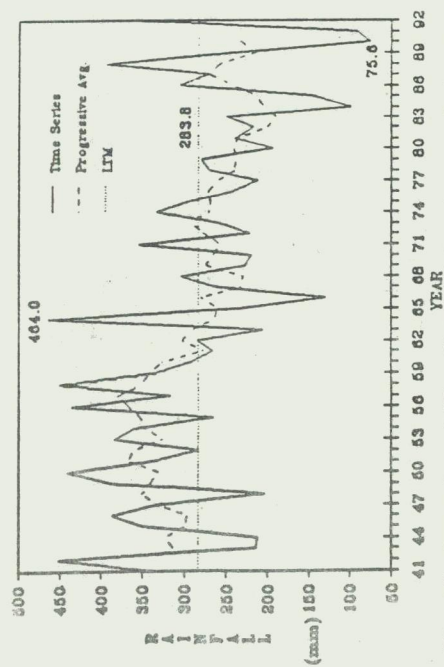


Fig. 16 Annual and Five Year Moving Average Rainfalls (Kessala)

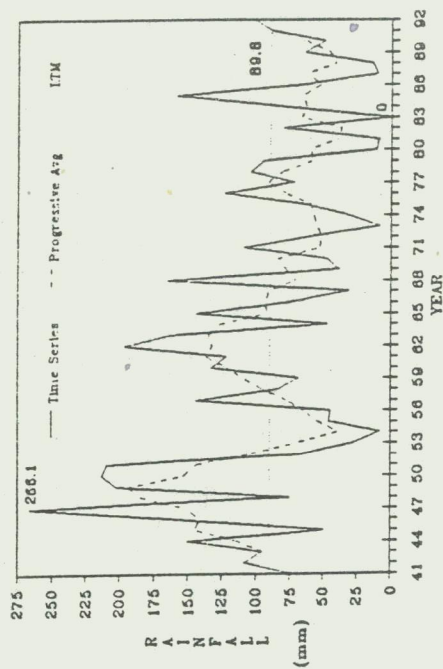


Fig. 15 Annual and Five Year Moving Average Rainfalls (Port Sudan)

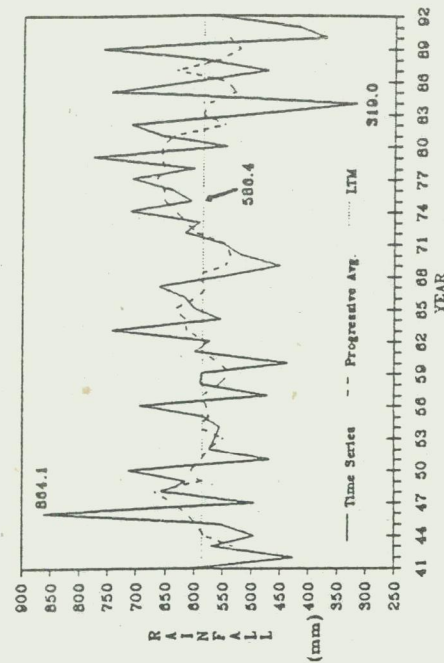


Fig. 17 Annual and Five Year Moving Average Rainfalls (El Gedaref)

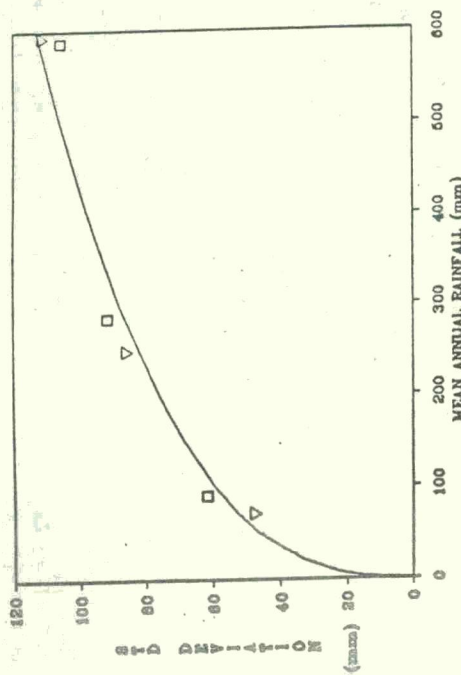


Fig. 18 Standard Deviation Versus Mean Annual Rainfall

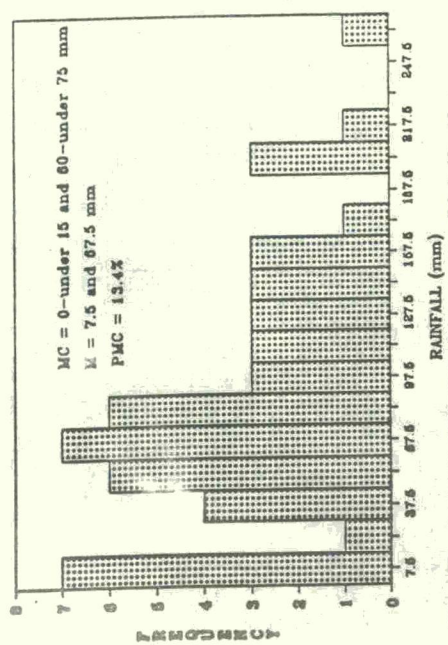


Fig. 20 Annual Rainfall Frequency Distribution (Port Sudan 1941-92)

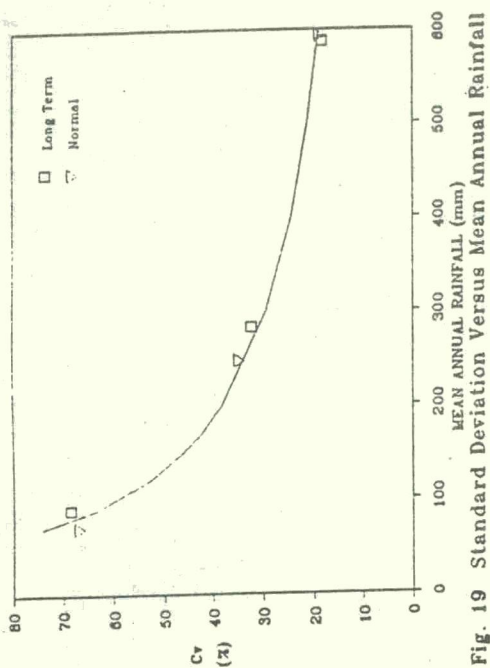


Fig. 19 Standard Deviation Versus Mean Annual Rainfall

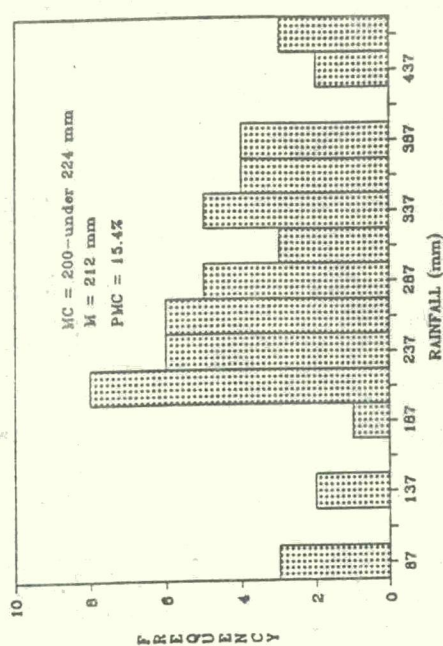


Fig. 21 Annual Rainfall Frequency Distribution (Kassala 1941-92)

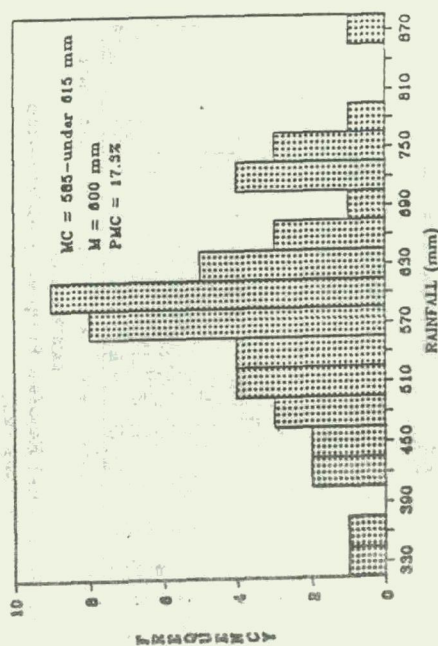


Fig. 22 Annual Rainfall Frequency Distribution
(El Gedaref 1941-92)

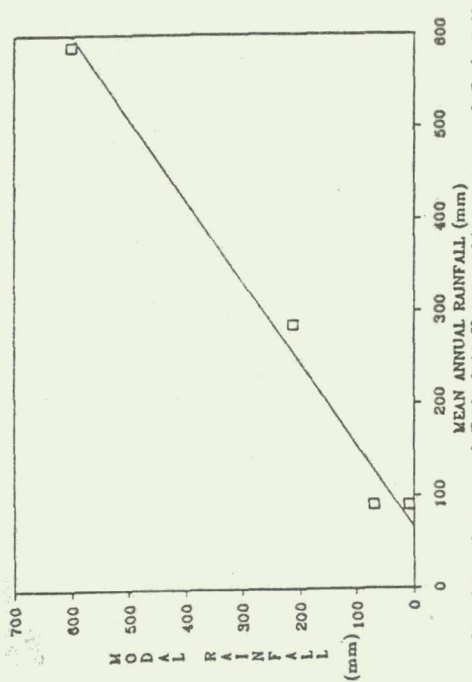


Fig. 23 Modal Annual Rainfall Versus Mean Annual Rainfall

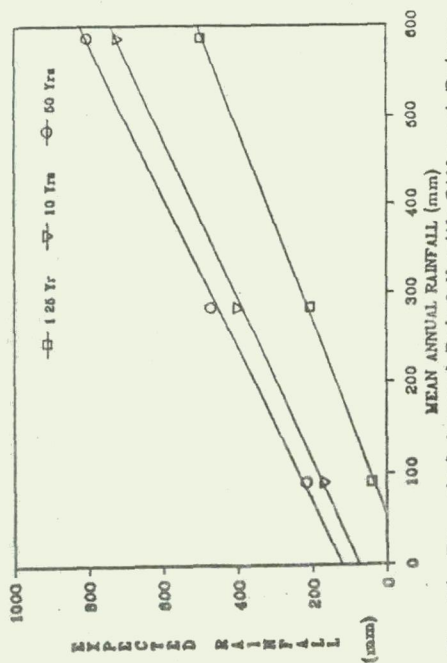


Fig. 24 Expected Annual Rainfall with Different Return Periods

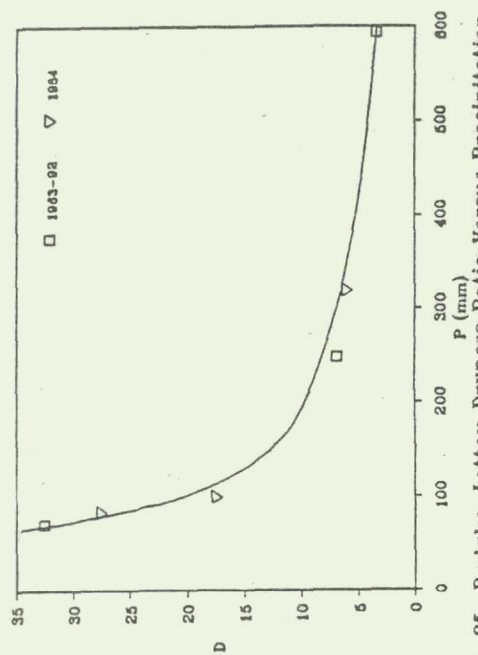


Fig. 25 Budyko-Lettau Dryness Ratio Versus Precipitation

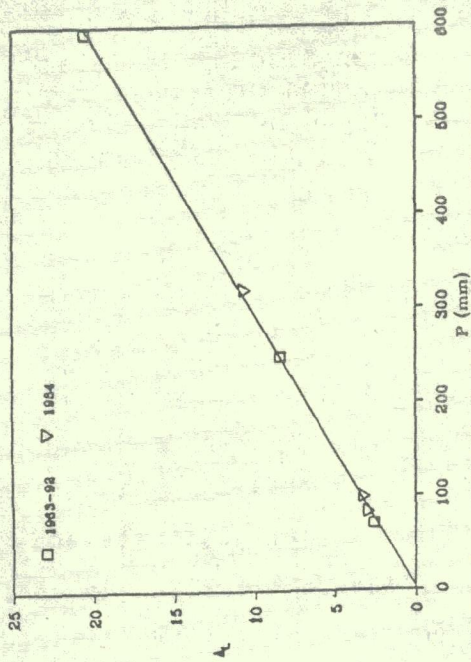


Fig. 27 Lang's Aridity Index Versus Precipitation

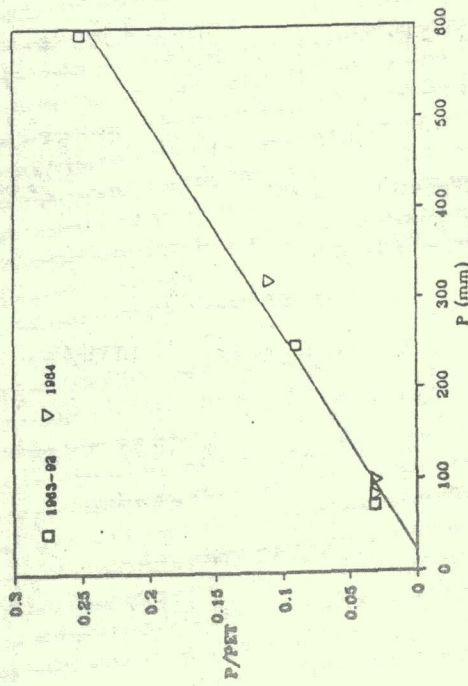


Fig. 28 P/PET Ratio Versus Precipitation

PRELIMINARY ANALYSIS OF THE USE OF THE RAINWATER IN HEBEI PROVINCE

Yu Fenglan

*Institute of Geography, Hebei Academy of Science &
Planning and Economic Commission of Hebei Province,
Shijiazhang 050011, China*

Qian Jinping

*Department of Geography, Hebei Normal University,
Shijiazhuang 050016, China*

To analyse the rainfall infiltration supply and its relationship with the change of the buried depth, the analysis from the change of the water ratio of the soil section in the process of the infiltration supply and the information for the flow of the water is conducted and the conversion relationship of rainfall, soil water and ground water is described.

1. Rainfall Infiltration Supply of the Ground Water Deep Buried Area in the Piedmont Plain

Ranzhuang is located in Hebei Piedmont Plain, $38^{\circ} 10' - 38^{\circ} 12'$ north latitude, $115^{\circ} 06' - 115^{\circ} 23'$ east longitude. The accumulated water covers an area of 53.1 km^2 . From west to east it is in long and narrow strip form. It is flat for the topography in the river basin. The ground is 23-45 m above the sea level, leaning from west to east, with the slope of 1 %. The average annual rainfall over many years is 560 mm, in which, the rainfall from July to September accounts for 86 % of the total. There are many factors which affect the rainfall infiltration. Under the deep buried of buried depth, the change of the size of the water holding storage capacity is mainly in the area from the ground to where the buried depth is 2

.8m (variable zone). Its change feature is mainly in the storage capacity of the tension water. Its physical meaning refers to the change of the water storage from the withering water ratio in suspended zone to the field water holding ratio. The maximum water storage can be up to 140 mm. The gravity water capacity is relatively small. The location with the buried depth of 2.5m to 2.8m is designated as the weak variable zone. In general, the water ratio maintains in the state of field water holding ratio and the change is very small. Only when there is fairly large rainfall and the supply intensity in the upper layer is greater than that of the lower layer, can this part of water storage capacity increase. The largest water storage capacity can be up to 60 mm and its main water storage is gravity water. The location with the buried depth below 5.5 m and above the ground water surface is designated as the relatively stable zone. It is in a state of the field water holding ratio of the whole year and the annual change is very small. For example, the rainfall infiltration supply process in July, 1988 showed the change of the water ratio.

In the first 10 days of July, there was discontinuous rainfall of 74 mm. The water storage in the variable zone above the buried depth of 2.8 m increased by 43 mm and that in the zone below 2.8m didn't increase. The rainfall from July 14 to July 17 was 163 mm in which the rainfall of July 17 was 94.8 mm and the water storage above the buried depth of 2.8 m increased to 110 mm. The ground water level continuously rose by 25 mm. Afterwards, because that the rainfall supply intensity was greater than the infiltration intensity. At the same time when the ground water was supplied by the rainfall infiltration, the water stored in the variable zone infiltrated and moved towards the weak variable zone to fill the gravity water storage capacity and to be stored there. The depth was up to 5.8 m.

When the rain period is over, the stored water went slowly downwards and went through the relatively stable zone above 5.8 m.

All moved downwards in the form of the water molecule progressive supplement to supply ground water in the whole year. The infiltration supply period could last until next year. The infiltration types were different with different depths. If the soil layer was above 5.6 m, the soil water moved slowly downwards in the form of infiltration to frontal surface. After reaching the area with the buried depth of 5.6 m the moving form the soil water began to change and the infiltration to the frontal surface gradually disappeared. In case that the water ratio maintained in stability and without changing, all the water moved downwards in form of the water molecule progressive supplement to make the ground water index rise. If it is calculated in accordance with water molecule particle movement formula and the buried depth divided by the infiltration factor, the time to begin the rising was at least 4-5 days after the rainfall started. However the actual observing information showed that the time to begin the rising started one day after the rainfall started. This showed that the total moving downwards in form of the water molecule progressive supplement existed.

As for the detail, please see Figure 1, the figure of the curve of the relationship between the annual rainfall and the supply factor.

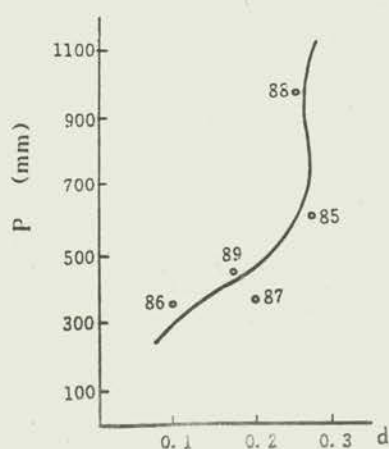


Figure 1. Curve of the Relationship between the Annual Rainfall and the Supply Factor

The curve was a reverse-curving one. The increase rate from 300 mm to 600 mm was fairly great. It tended to become stable over 600 mm. From 800 mm, it began to become reverse-curving. This change was in keeping with the general inference relationship for rainfall infiltration. Therefore, under the deep buried condition, the change of the soil water ratio vertical section, the storage capacity of the tension water was not limitless in extending downwards. The water ratio tended to become stable when it reached to a certain depth. The buried depth of the ground water in a certain range reflected the size of the water storage capacity (including the storage capacity of the tension water and that for the gravity water). When the buried depth was close to the ground surface, the water storage capacity was very small. At this time most of the rainfall converted into surface runoff. Therefore the supply was not very great. When the buried depth increased, the water storage capacity increased with it. In case that there was a certain quantity grade of rainfall, the infiltration supply increased with it. Therefore the supply coefficient of the rainfall infiltration increased with the increase of the buried depth. However there was a certain limit for the increase of the water storage capacity. If the buried depth increased more, the change of the water storage capacity was very small. Therefore the infiltration supply factor did not change with the increase of the buried depth. Since in the deep buried area, the water storage capacity in the suspended zone increased, it was a fairly long time for the after-retarding of the sub-precipitation supply. In addition to the fairly great storm, after the general rainfall, there was no obvious infiltration supply to make the ground water level rise. Because the increase of the regulation function of the water storage capacity in the suspended zone made the time of the infiltration supply become prolonged, the year with fairly large rainfall might affect the supply in the next year. This was also a feature of the change of supply in the deep buried zone.

2. Back Irrigation with the Diversion of the Infiltration

there was not runoff produced in July with the total rainfall of 299.9 mm and 167.4 mm in the first ten days of the month. The infiltration was $959,000 \text{ m}^3$ calculated with the infiltration factor of 30 %. Calculated with the water storage length of 500 m in Gaoyang Section of Old Yanghe River Course, the infiltration diverted for back irrigation is $1,723,500 \text{ m}^3$ in the east bank of Old Yanghe River. The total of the river and the rainfall infiltrations is $2,682,500 \text{ m}^3$. Thus the rainfall infiltration supply accounts for 35.7 % and the side supply of the river accounts for 64.3%.

3. Analysis of the Rainfall Infiltration Supply Factor

Using the information of P , the annual rainfall of 1974- 1981, Δ , the ground water buried depth before the flood period, d , the annual rainfall infiltration supply factor, the multi-station comprehensive method over years with different lithological characters is used. Please see Figure 2.

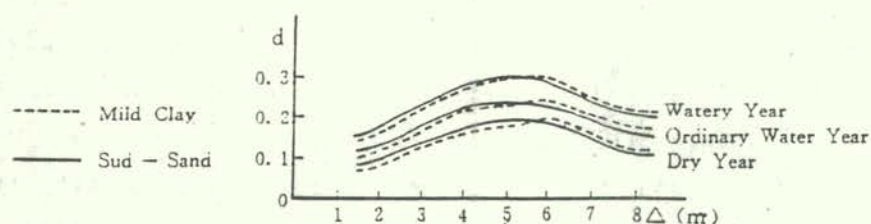


Figure 2. Relationship of d, P, Δ

It can be seen from Figure 2 that being different from the sub-rainfall infiltration supply, there is still infiltration supply in the year when the buried depth is zero before the flood period, and the annual rainfall infiltration supply factor increases with the increase of the annual rainfall. In the same grade of rainfall, when the buried depth of the ground water before the flood is fairly small, the annual rainfall infiltration supply factor increases with the increase of the buried depth of the ground

Water for Extending the Source of Water in Helonggang Area

The features for the climate of Helonggang Area are that there is much water in the rainy season and less water in the dry season which make the sources of water very imbalanced in distribution. It is necessary to extend the use of the sources of water to change the climate features of being mainly dry in spring, waterlogged in summer and with less water in autumn. It must be done to use the atmospheric water, surface water and ground water together. Mutual conversion, giving play to the strong points and avoiding the shortcomings, mutual supplement are used. In the rainy season, there is more water. In case that there is no waterlogging, no muddy soil and no alkaline, to use the rivers canals, ponds, lakes to stop and store the surface runoff to extend the sources of water which can reduce part of the runoff to flow eastwards to the sea and also can give full play to the side infiltration capacity of the ponds, lakes and rivers as well as the canals to divert the water for the supply of the ground water. The exploration of and the supply of the ground water are mutually limited. Only exploration and no supply will cause the great dropping of the ground water level and the source of water will be damaged while only supply and no exploration will cause the shallow ground water level to rise sharply. The land will cause muddy soil and have saline occurring which will make the water become saline and the soil become alkaline and cause the reduction of the agricultural output. The combination of exploration and supply should be conducted to strength the water circulation and harness the draught, waterlogging, alkaline and saline. Thus the production of industry and agriculture can be promoted to develop steadily. With the observation of the of the rainfall Station of Shicun Commune (3-5 li away from Gaozhuang Section) of Hejian County as an example, the effective rainfall from March 1 to September 1, 1981 was 383 mm. Because of the successive draught for several years, the ground water level was low and the buried depth was 6-7 m. Not only the small rain didn't produce the surface runoff, but also

water before the flood period. When the buried depth of the ground water is fairly large, the annual rainfall infiltration supply factor decreases slowly with the increase of the buried depth of the ground water. Therefore, the optimum buried depths for the mild clay in the watery ear, ordinary water year and dry year are 5.31, 5.18 and 4.87 respectively. It shows that with the increase of the annual rainfall, there is the tendency of increase for the maximum depth. When the ground water level is stable, the annual rainfall infiltration factor increases with the increase of the annual rainfall. And the spaces for the three lines for the year of watery, ordinary water and draught gradually become larger with the increase of the ground water level. Comparing the relationship line of the mild clay and sub-sand, in the same grade of the annual rainfall, the buried depth of the ground water before the flood is in left side close to the optimum ground water level of the mild clay. The value of the annual rainfall infiltration supply factor is less than the annual rainfall infiltration supply factor. Due to that the water storage capacity of the mild clay is smaller than that of the sub-sand in the same buried depth, when the buried depth increases to over the optimum buried depth, the water loss of the non-saturation zone plays the leading factor. Due to that the lost water in the mild clay is less than that of sub-sand, the supply factor of the mild clay at this time is larger than that of the sub-sand. The result also leads to the same grade of rainfall and that the optimum depth of mild clay is larger than that of the sub-sand.

Just as in the ordinary water year, the optimum buried depth is 5.18 m for the mild clay and the optimum buried depth for sub-sand is 4.72 m.

For the effect of the concentration of the rainfall in a year on the rainfall infiltration supply factor, if the soil quality is similar, the buried depth, the grade of annual rainfall are the same, the rainfall concentration in a year has obvious effect on the annual rainfall infiltration supply factor. The proportion of

the maximum rainfall of 30 days in the year and the annual rainfall β is used as an index to show the rainfall concentration in the year. Please see Figure 3.

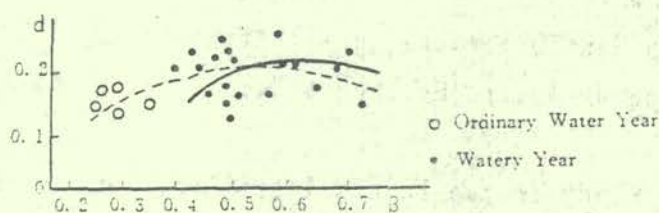


Fig. 3 Relationship between d and β
in the Same Buried Depth

It can be seen from Fig. 3, the main supply in the year mainly occurs in the flood period of June to September. At this time the higher the rainfall concentration β is, the rainfall shown is relatively larger and more the supply remained after meeting the needs of the lost water in the soil is, more chances there are for the occurrence of return storage, the shorter the intervals is for the sub-rainfall, the decreased it is for the soil lost water, to make the supply become increased. With the further increase of the value of β , the proportion of the surface runoff increases to start playing the role of controlling in a certain degree the annual rainfall infiltration supply factor and to make the annual infiltration supply factor become lowered. Comparing the watery year and the ordinary water year, if the annual rainfall increases, the value of β increases in general. Therefore the value of β in watery year is higher than that of the ordinary year. In a word, the use of rainwater in Hebei Province can be up to 30 % - 40 % or so.

Reference

- [1]. Cao Wanjin, Study of the Rainfall Infiltration Supply Factor in Plain Areas, Study of Source of Water in Plains, Xuelin Publishing House, 1985
- [2]. Liu Keyan, Wang Huanbang, Preliminary Analysis of the Annual Rainfall Infiltration Supply in the areas of Hebei Plain, < < Hydrology >>, NO. 3, 1988
- [3]. Lu Zheng, Wu Shan, Diverting Infiltration for Back Irrigation to Extend the Source of Water, "Science & Technology of Haihe River", NO. 2, 1982
- [4]. Qiu Jingtang, Study of the Rainfall Infiltration Supply in the Deep Buried Areas of the Piedmont Plain of Hebei Province, <<Hydrology>>, NO. 5, 1993

Secton 4

NATIONAL OR REGIONAL EXPERIENCES

RAINWATER UTILIZATION IN SEMI-ARID HILLY REGION OF NORTH CHINA

---A Case Study from Yuanshi County of Hebei Province

Wu Jingtang

Director, Water Conservancy Bureau of Yuanshi County, Hebei Province, 050026

Mou Haisheng

Dept. of Urban and Environmental Sciences, Peking University, 100871 China

ABSTRACT: By reviewing the long-term struggle with the drought and studying wide, thorough practice of rainwater utilization, the authors conclude that the utilization ways of rainwater resource and development mode of rainwater agriculture for semi-arid north China are "to develop rainwater collection, storage and saving simultaneously". The regional water crisis is becoming more and more serious and it has limited the social development. Facing at this problem, the authors propose water resources development strategies and the long-term regional water control measures which take the rainwater as the main sustainable utilization body.

I. GENERAL INFORMATION OF YUANSHI COUNTY

Yuanshi county is situated at the longitude of 114-11' to 114-39'E and latitude of 37-41' to 37-56'N. Its geomorphological features are as followings: In its west hilly region, there are many hills and valleys; in its east, there is a flat plain which belongs to the alluvial sloping plain of Tanhang mountain. With a continental monsoon semi-arid climate, its perennial average temperature is 12.6°C, the highest temperature is 42°C and the lowest is -25.3°C. There are three rivers across Yuanshi county. They are Beisha River, Zhulong River, and Huaihei River. After 1970's, all of them have dried up. The total area of the whole county is 68 square kilometers. There are 539 thousand mu cultivated land, including 382.7 thousand mu effective irrigation area which accounts for 71.1% of the total cultivated area. There are 25 towns, 208 village committees, 236 natural villages in the county and the total population is 360 thousand. (Fig. 1: Geographical location map of Yuanshi county). Because of the frequent drought and flood, the local people have been taking water control (especially, the development and use of rainwater resources) as an important activity for promoting county development for a long time.

II. DEVELOPMENT AND UTILIZATION OF RAINWATER RESOURCES

2.1 Rainwater Resources



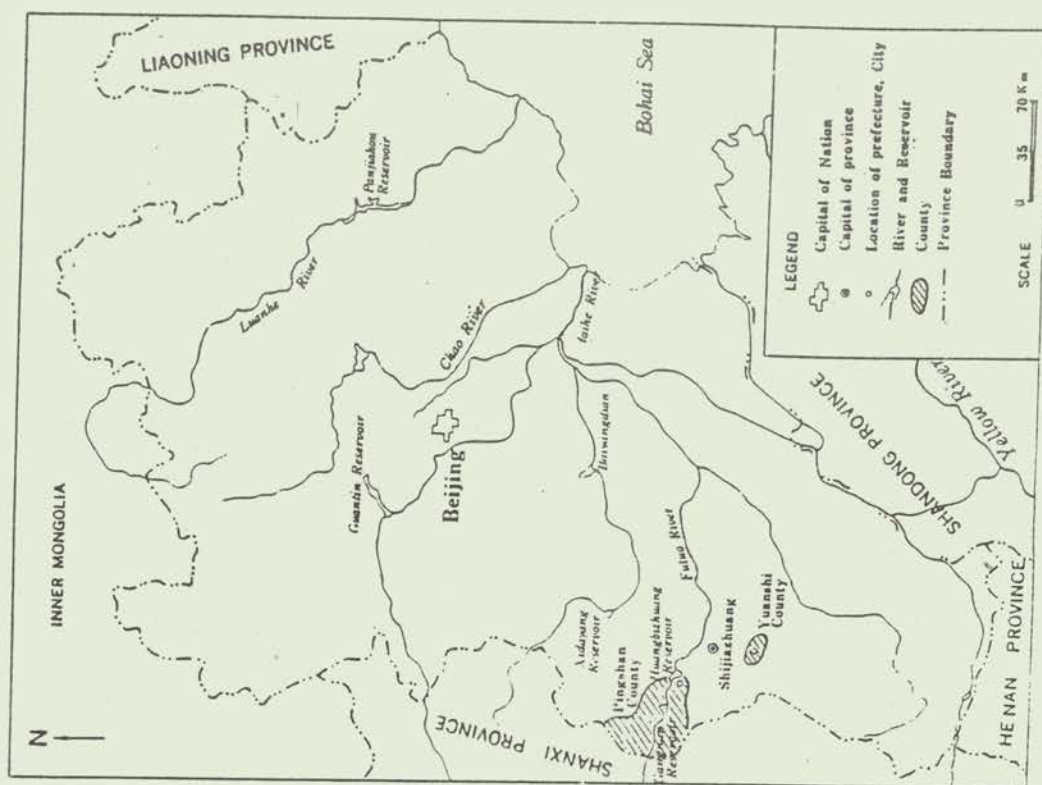


Fig. 1: Map of Geographical Location of Yuanshi County, Bebei Province

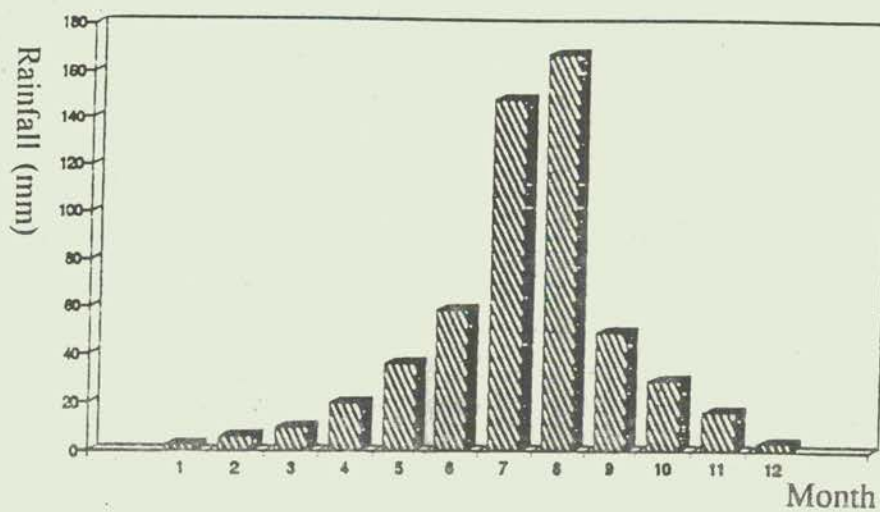


Fig. 2: Perennial Rainfall Process Curve of Yuanshi County, Hebei Province

The perennial average rainfall is 588.9 mm and its distribution in time and space is not even. The average rainfall of the west hilly region is 572.2 mm and the average rainfall of the plain is 565.7 mm. The precipitation varies greatly between years; the maximum rainfall is 1412.0 mm in the hilly region and 1381.2 mm in plain (in 1963), the minimum rainfall is only 253.4 mm in hilly region and 188.5 mm in plain (in 1972). The rainfall's distribution in a year is also not even. The perennial average rainfall in July, August is 304.3 mm, accounting for 53% of the total rainfall. The rainfall, in spring sowing period (April and May), is very little, only 4.8 mm, accounting for 0.8% of the total rainfall. Thus, Spring drought occurs frequently and limits the industrial and agricultural production. (Fig. 2: Perennial rainfall process curve of Yuanshi county). By analysis and calculation, annual rainfall under different guarantee rate and the total rainwater resource of the county are shown in table 1.

Tab. 1: Annual mean rainfall and rainwater resource at different guarantee rate and the total rainwater resource of Yuanshi county

Divisions	Area (Km ²)	Rainfall(mm)/Water Resource(10 ⁹ M ³)			
		Mean	P=50 %	p=75 %	P=95 %
Mountain & Hilly Region	324	567.7/ 1.854	533.0/ 1.715	420.0/ 1.3193	312.0/ 0.9534
Plain	357	562.6/ 2.020	529.0/ 1.880	416.0/ 1.4547	309.5/ 1.0635
Total	681	568.9/ 3.874	523.0/ 3.562	398.0/ 2.7104	284.0/ 1.9340

Table 1 shows that rainwater resources of Yuanshi county is very considerable. Its perennial mean precipitation is 568.9 mm and the average annual total amount is 387.42 MCM. But with the industrial and agricultural development and the great increment of water demand, the water crisis has taken place in recent years. By the investigation on present status of water resources, the total amount of water resources of the whole county is 152.21 MCM, among which 54.89 MCM is surface water resources and 98.32 MCM is underground water resources. However, the current demand for water is 190.597 MCM (at 50% frequency), and 231.14

MCM (at 75% frequency). The difference between water resources demand and supply is 40- 80 MCM. Considering the transfer rate of rainwater resource is far less than 1, it is apparent that water supply is not enough in general year.

2.2 Rainwater Utilization Ways

Rainwater utilization in Yuanshi county has a long history and this widespread traditional technique has been continuously developed. The utilization of rainwater in the area can be divided into two stages: Before 1950's, the first-level utilization of rainwater played the main role, and various small projects of collecting and storing rainwater had been properly constructed; After 1950's, excavating ponds, constructing dams, digging wells had become the main and general ways of rainwater utilization. At present, the whole county have already had 1000 projects for collecting, storing and saving rainwater, among which 34 are middle and small reservoirs, 2 are large-sized conveyance canals (trans-basin conveyance) and others are dams, ponds, pools, water cellars, Dangwas, etc. The small projects can be found all over the hilly region. The total storage capacity is about 100 million cubic meters, but the actual utilization amount of rainwater is far less than 100 million cubic meters (only 25% of the total of rainfall). (Fig. 1: status of rainwater utilization projects, Yuanshi county). The main ways of rainwater utilization in this county are shown as follows:

2.2.1 Water-Jar

Water jar well, the traditional way of rainwater utilization in Taihang hilly region of north China, usually has the diameter of 1.5-3.0 meters, the depth of 4.0-6.0 meters and a shape of circle or square. It is composed of well floor, wall and top cover. The whole well is built in three-mixed soils and brick concrete. Its wall has a seepage-proof layer of 0.2-0.3 meters. Its top cover is semicircular. There is a circular hole in its wall to collect rainwater. The water-jar well is mainly used to supply water for agricultural production, people and domestic animals.

2.2.2 Water Tank

Water tank, in a shape of circle and square, is a widespread traditional rainwater utilization way in this area. Its depth is usually two meters or so and has a different storage capacity from several decades cubic meters to several hundreds cubic meters. It is composed of floor and wall. In the hilly region, it is built in rock with mud to prevent seepage, and in the plain built in three-mixed soil. Besides the tank, there are import and outpost to collect and pump rainwater.

2.2.3 Pound

Because rainwater infiltrates quickly in the hilly region with sandy soil, the underground water level is very shallow. The river is wide and shallow and its surface is often dried up. Yet, the underground runoff is very plentiful (coming from rainwater seepage). In this region, it is easy to dig pound (well with big mouth) built in rock. The pound is in a shape of circle or square, with the diameter of 3 to 10 meters and the depth of 10 meters or so. It is built to store rainwater and collect underground water, supply agricultural irrigation and drinking-water for the people and domestic animals. With the advantage of easy digging and large water amount it collects, it is widely used.

2.2.4 Mini-Dam

Mini-dam, also a rainwater utilization way in the hilly region, is built in valleys and gullies, composed of water-proof wall and water outpost. Being built easily, it doesn't need seepage-proof disposal and its volume is usually less than 10 thousand cubic meters. It is mainly used to keep rainwater of valleys and gullies and supply water for agriculture and animal husbandry.

2.2.5 Reservoir

Reservoir is the key water project of rainwater use, obstructing flood and storing water, based on its design capacity, it can be divided into small-sized reservoir, middle-sized reservoir, large-sized reservoir. Being a large-scale project, its structure is more duplicated. There are only middle and small-sized reservoirs, the common design capacity is 100-80000 thousand cubic meters in Yuanshi county

2.2.6 Silt Arrester

Silt arrester are more built at the middle and upper - reaches of the valleys, mainly to form the little plain of mountain areas by using the flood of wet season, and to control water and soil loss.

2.2.7 Snow Collecting

Collecting snow to field is another way of winter rainwater(snow)use in the water shortage regions of North China. It is simple and carried out easily, in the other words, it is to collect the snow from where are not fields, such as villages, roads and courtyards to fields, so as to benefit the winter wheat and increase water amount for the farming fields

2.2.8 Roof-cistern system

Roof-cistern system is a rainwater utilization way of every family in the area. By roof area, after going through the gathering trough and collecting pipe, rainwater enters storage cistern. In the past, it used to provide water for washing clothes, irrigating pigsty. With the lack of water resources day after day and further perfection of the catchment system, this way will be gradually developed to court economy and supply drinking water for people and domestic animals.

III. The Development Pattern of Rain-fed Agriculture in the Hilly Region

Rain-fed agriculture has not only been the traditional farming way for several thousand years, but also is the development direction at present and in the future. Although it has not been improved to the advanced theory of rain-fed agriculture in the past when ploughing and sowing depend on the heaven to have enough to eat and wear, it is really full of connotation of rain-fed agriculture. At present, the land distribution and the farming ways not only show the continuation of the rain-fed agriculture, but also establish an embryonic for the development and research of standard rain-fed agriculture.

3.1 The Design of Rain-fed Ecological System in Slope Fields

There are a lot of "gully slope fields" in the low hilly region of the Taihang mountain range. Owing to human beings' activities, the vegetation covering rate decreases. In the period of heavy rain, the vegetation collects little rainwater and aggravates flood as well as soil and water loss. In the period of drought, with high elevation and difficult irrigation, the fields can not yield high productivity.

According to the traditional way, we can only irrigate these fields by sprinkler and pipe, but without enough economic and social capacity it is impossible to realize it at present, even in several years later. Taking the advantage of rainwater utilization, the authors design a rain-fed eco-system for the slope fields in semi-arid regions. The gully and slope fields include two types: one is hillside field at the foot of low hills. It is flat and has a large area, but it is difficult to conduct canal irrigation due to its specific features of slope and geographical position. First, its soil grain is big, including sands, rocks, gravels through which water can seepage; Second, with high terrain, it is difficult to convey water. Certainly, due to long-time cultivation, it is possible for some rich fields to carry out sprinkle or irrigation. At Yuanshi county, there are a lot of these kinds of fields, most of which are wastelands or coarsely-cultivated lands belong to opened up land and coarse cultivated lands because there are not enough water sources.

The design thought for rain-fed ecological system of the slope fields is as followings: changing the disadvantage (water shortage) to advantage. At first,

consider the slope fields and gathering areas of adjacent hilly slope as a whole. A basically closed system of the slope fields can be divided into water source protection area by afforestation at the upper part of the hills, water collection area at the middle part, cultivation area at the low part. According to the soil quality good or not, different brushes and grass are planted in the water source protection area in order to retain water and soil weathering matter. Catchment projects such as pools, water jars, etc, have been constructed in the water collection area to store some water for crops needed in drought or in a critical period. In cultivation area, effort should be done to smooth land, to improve soil structure and capacity for retaining water. At the same time, the soil thickness at the edge of the slope lands should be increased to prevent losing water.

The outline for running rain-fed eco-system of the slope fields is as follows: In general year when there are plentiful rainfall or moderate rainfall, depending on water stored by itself and collected by the water source protection area, the slope fields supply water what the crops need to grow. The water collected from the water collection area is used to meet the water demand of the sowing and agricultural irrigation in the next year while the source of rainwater for the slope fields is two or one times than water collected by itself area so that there is water storage in the system; when the year of shortage water comes, the storage water from the slope could supply the demand of the slope fields, under this situation, the source of water for the sloping fields is two or three time than water collected by itself area. According to the crop species, cultivation system as well as regularity and density of rainwater, the area proportion of three parts and the size of storage facility in water collection area can be designed. According to the specific situation of Yuanshi county, the area proportion of the three parts is 3: 1: 1; The volume of the facility is about 500 cubic meters per mu. Rain-fed eco-system of the sloping fields can not only control soil and water loss, prevent leaking water, improve the soil fertility, but also increase the vegetation covering rate, improve the guarantee rate of crop production. The water collection area and catchment project in the middle part have the function to adjust, collect and store rainwater of itself and from the upper-reaches. Proper irrigation by using the stored water could effectively lighten the drought. In the period of heavy rain, they could prevent flood and adjust runoff. Rain-fed eco-system for the slope fields can recover vegetation, combine using fields with resting fields and improve ecological environment and increase the land load capacity of the fields so as to achieve the compressive efficiency. This is the effective measure for sustainable development of rainwater resources in the slope fields.

3.2 The Design of the Rain-fed Agriculture in Valleys and Gullies

In the hilly region of Yuanshi county, there is another way of land utilization--hollow fields in valleys and gullies. These are odd land pieces reclaimed at precipitous hill-slope and low middle parts of the wide gullies. Its soil basis is debris which are gathered from the gully slope. Usually, drought-enduring crops are cultivated once a year and their yield is all dependent on the rain condition. This part of land should be covered by trees, however, owing to no possibility for afforestation, there is only little grass and brush on the upper slope on bared rock. But under the reasonable design and improvement, this part of land can play certain efficiency.

Rain-fed sloping hollow field system is designed from the point of rainwater utilization. The design thought is: Like rain-fed sloping land system, this system is divided into two parts, except that it does not include water collection area because that the steep ground and slope area do not permit. The whole area from upper sunken slope to mountain ridge is water collection and afforestation area to conserve water. At the foot of hollow slope, small blocks of fields are leveled to store water from the upper part. The area proportion between both parts is greatly restricted by topographic condition to comply with the nature. The cultivated land should be reclaimed as low as possible and as small as possible. The thick and wide fields are constructed at the edge to prevent losing water. The system is rather called as eco-protection measure than as agricultural development mode. It has more significance of environmental protection. In addition, dams at valleys and gullies and slope fields are the traditional ways to collect and store rainwater in Yuanshi county.

IV. Adjusting Underground Reservoir by Rainwater

In order to relax the water resource crisis of this region, the measures for reasonable adjustment of rainwater resources and sustainable development in the plain in front of the hills are searched and a way to recharge underground reservoir by rainwater is found. In 1989, Yuanshi county began to do experiment on artificial recharge of underground water by natural river in the plain. In the paper, based on original test, the underground reservoir's potential capacity to adjust and store rainwater is discussed.

4.1 The Feasibility to Recharge Underground Reservoir By Rainwater

Artificial recharge of underground water needs enough water sources and certain hydro-geological condition. Though the rain fall is not plentiful in Yuanshi county, it occurs centrally and more than 70% rainwater falls in June, July, August. The rainwater is so large that flood takes place often. Therefore, in the flood season of every year, there is a certain amount of flood runoff. This part of rainwater

supplies water to recharge underground water. In addition, two large trans-basin diversion canals had been built in 1970's in Yuanshi county.

Suitable recharge place and storage reservoir is another condition for rainwater to effectively recharge underground reservoir. There are three wide and shallow rivers across Yuanshi county from the west to the east. These rivers, whose cover layers have good percolation, provide the places for rainwater to recharge underground water. These areas are all suitable places for artificial recharge of underground water. The domestic and abroad practice of artificial recharge of underground water has proved that suitable underground storage reservoir requires that the thickness of aeration zone is 10-20 meters or so because it controls the underground reservoir capacity.

At Yuanshi county, in the plain in front of the hills, at the lower reaches of "Bayi reservoir and Yingang canal, there are two rivers, Baisha River and Zhulong River, which control three blocks of fields between rivers. The total area of these fields is 200 square kilometers, among which cultivated-fields is 23 thousand mu. Their hydro-geological features are described in the followings: The shallow water-holding stratum is composed of 3-5 single layers, with thickness of 7-30 meters, average thickness of 15.7 meters; The minimum depth of upper layer of water-holding stratum is about 13 meters, the maximum depth of lower layer of water-holding stratum is 54 meters; The water-holding stratum is mainly composed by gravel and mid-coarse sand of the quaternary, the feature of water power is concealed water. Affected obviously by precipitation and surface water, the underground water level decreases progressively from the west to the east. The water power slope is 2.7/1000 on average, the cover stratum is mainly composed by clay and sandy soil, which have good infiltration. In this region, the depth of underground water falls from 11.9 meters averaged in 1979 to 22.02 meters in 1989. The dried thickness of the water-holding layer is 10.12 meters and the underground reservoir capacity is 500 million cubic meters, which is as much as twice of the total average rainfall. So the hydro-geological condition is suitable for rainwater recharge.

4.2 Recharge of Underground Water by Infiltration of Natural River Bed

The Baisha River, one of the three largest rivers across the whole county, is a seasonal river lying 13 kilometers away from the north of the county. Its drainage basin covers 8 towns and its total length is 39 kilometers. Its river bed is narrow, only about a hundred meters and may reach half a kilometer at the widest place. With complicated growth form and varied topographical form along the bank of the river, the river bed has accumulated thick polavium whose quality and distribution vary complicatedly. At the same time, it is affected by human being's activities such as

reclaiming land, excavating sand and soil. In addition, there are roads and bridges. After all, it belongs to an ideal place for infiltrating and storing water. The data of drilling shows that the main sand and cobble river bed has average thickness of 10-20 meters, under which there is a gravel-clay layer. The gravel-clay layer becomes thinner and thinner progressively from Zhancun reservoir to Malum bridge near Jin-Guang railway. The maximum thickness occurs between road at Ti village and at Liao village. From there it tends to become thinner again, with smooth sand cobbles mixing unevenly. The parts near the river have bigger cobbles, especially in the south of the Baisha River.

4.3 Efficiency Analysis for Recharge of Underground Water

Based on the experiment of the recharge on the Baisha River in Yuanshi, in 1990's, the total recharge of underground water is 16,671,800 cubic meters; the underground water level within the observing area rises 5.60 more meters on average than before the experiment, the benefit range involves 11 townships and 61 natural villages, with total area of 200 square kilometers, including cultivated land 230 thousand mu. The underground water level rises differently with the maximum of 14.74 meters. Owing to the raise of the underground water level, 1200 wells get supplement, 783 wells which had dried up for many years could be used again. 300 wells do not need renewing and if one well costs 400 yuan, more than 4 million yuan will be saved.

Within recharge area, there are 167 thousand mu cultivated fields, including 107 thousand mu well-irrigation area. According to the irrigation quota of 450 cubic meters, the underground water level rises two meters on average. For three years, total 170 million ton meters pumping power and 510 thousand yuan irrigation investment have been saved. With the rising of the underground water level and the increase of motor-pumped wells, the guarantee rate of irrigation ascends. According to statistics, yield increases 97.37 kg/mu in the recharge area, output increases 63.8782 million kg and output value increases 39.9782 million yuan. 80 million cubic meters underground water has been stored in Yuanshi county by the Baisha River recharge.

V. Sustainable Development Strategies For Rainwater Resources Utilization

According to the assessment of rainwater resources of Yuanshi county, its average annual total rainfall is very considerable. In general year, it can reach 387.42 million cubic meters. But what is being used is less than 90 million cubic meters (including the amount which is transformed into underground water). Its utilization rate is near 25%, only accounting for 50% of the water resources which could be

used and developed at present. As a result, it becomes unavoidable that water resources shortage and the water crisis in different degree will occur in this region. Even though there are 20-30 million cubic meters diversion water which are diverted by trans-basin conveyance project, because water supply and demand is out of proportion and the phenomenon of water wastage is still serious, if the new effective water-control measure could not be adapted, the water crisis would not be conquered but becomes more serious. Above all, with development of the social economy and increase of population, in order to realize the goal of a good life, with industrial and agricultural production output value being doubled and doubled in this region by the end of this century, water becomes an important restriction factor. As a result, dealing with the actual situation of Yuanshi county, it should be made as a basic contra-measure in the future to develop excavation, storage, diversion simultaneously and to put equal stress on construction, management and protection, including several aspects in detail as follows:

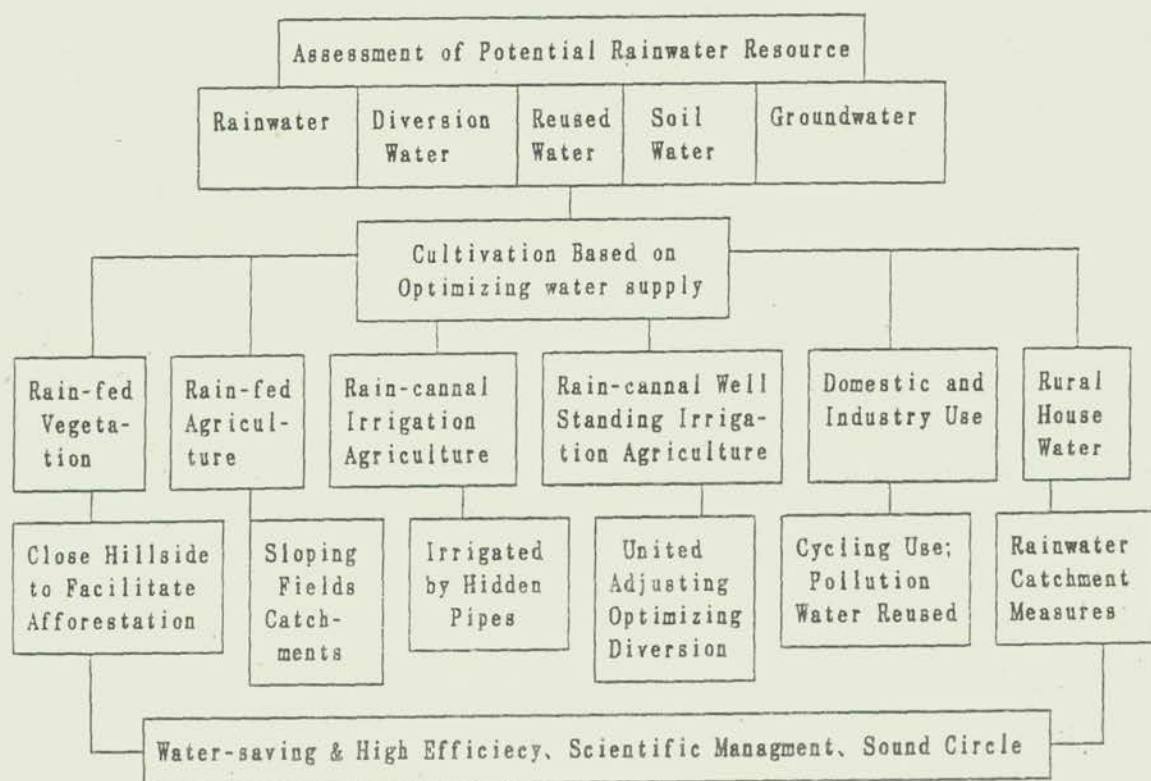


Fig. 3: Effective Utilization Model of Water Resources for Yuanshi County, Bebei Province, China

1. The emphasis on water conservancy construction in the hilly region should be put on tapping potentiality of the existing conservancy projects and combining excavation with storage. Its thought is that while developing the rainwater catchment system in the slope fields as a main project, fully using hilly lands superiority, devote major efforts to develop watershed-control and close hillside to facilitate afforestation, sow grass and so on. In addition, attention should pay be paid to improve the techniques of roof and courtyard-cistern system to relax the difficulties of family economy and provide drinking water for people and domestic animals. Finally, rain-fed agriculture system is perfected in mountainous areas by the way of increasing the utilization rate of water resources.

2. In the hilly region, when strengthening and developing successful experience of comprehensive utilization of rainwater, surface water and underground water, the conveyance system of fields and irrigation techniques as well as optimizing adjustment for water resources should be made as the main direction and progressively brought into orbit of standardization and scientification.

3. When the rainwater collection to increase infiltration and agriculture water saving irrigation are placed on the important agenda in the plain region, water-saving techniques and institution of water use should be activity spreader in industry and household as well as other aspects.

4. Recharge of underground reservoir by using rainwater, and storage of water resources should be made as a long-term water control strategy in the plain region of Yuanshi county.

References:

1. Mingyue Luo, 1990, Research of Rainwater Utilization in Arid and Semi- Arid Regions, the Technique of Water Conservancy and Power of Gansu Province, Water Conservancy Department of Gansu Province, P. R. China, No.4
2. Liu Changming and Mou Haisheng, 1993, Rainwater catchment system in agricultural regions of North China, Agricultural System and Ecology.
3. The water conservancy record of Yuanshi county (submitted text), Edit-House of the Water conservancy record of Yuanshi county. June, 1990.
4. Report on the long-term water supply plan of Yuanshi county, water conservancy bureau of Yuanshi county, Hebei province, P. R. China. Feb. 1993.
5. Wu Jingtang, 1993, Test research of artificial recharge of underground water through natural river bed in the pied-mount plain, Journal of Hebei Geological College, the City of Shijiazhuang, P. R. China. No.1.
6. Mou Haisheng, 1994. Rainwater Utilization: Theory and Its Applization(Ph.D. Paper), Institute of Geography, Chinese Academy of Sciences

RAINWATER CATCHMENT SYSTEMS IN TEXAS

J. Hari Krishna
Senior Hydrologist
Texas Natural Resource Conservation Commission
P.O. Box 13087, MC 150
Austin, Texas 78711-3087
U. S. A.

INTRODUCTION

Rainwater harvesting is not an entirely new concept. In the early part of the twentieth century, there were many cisterns in Texas (and in some other states as well), which were used to collect rainwater. This was particularly true in remote regions where there were no other readily available water sources. As groundwater exploration and use increased in Texas, the practice of harvesting rainwater and using it for domestic purposes became obsolete.

In recent years however, rainwater harvesting is again receiving attention due to several reasons. One important factor is the increased awareness of our environment, and the desire to protect and conserve natural resources such as rainfall. Also, in areas where both groundwater and surface water resources are inadequate in quantity or unacceptable in quality, rainwater is the only obvious choice for domestic water supply.

There are possibly a number of rainwater collection systems in Texas, however this paper will be limited to some prominent facilities in Austin, and in the Central Texas region.

RAINFALL CHARACTERISTICS

The average annual rainfall in Austin, Texas is about 32 inches (approximately 810 mm). Long-term records indicate that some rainfall occurs in every month of the year, however a bi-modal rainfall pattern is evident. A peak occurs in May/June with a

combined rainfall total for the two months averaging 7.3 inches (185 mm), followed by another peak in September/October with a combined total for those two months averaging 7 inches (178 mm). The rest of the rainfall is distributed throughout the year. A number of high-intensity short-duration storms are received particularly in the Spring, when considerable amounts of runoff could be captured.

RAINWATER HARVESTING POTENTIAL

The roof areas of homes in the Austin area can typically range from about 1500 sq. ft. to about 3,000 sq. ft. Using a relatively small home with a roof area of 1800 sq. ft. as an example, it has the potential to harvest 4,800 cft. ($1800 \text{ sq. ft.} \times 32 \text{ in.} \times 1/12 \text{ in./ft.}$) or almost 36,000 gallons of water per year. This provides approximately 100 gallons of water per day on average, for a household. For a home with a couple and a child, the system can provide about 35 gpcd (gallons/capita/day).

SIZING OF RAINWATER CISTERN SYSTEMS

The required capacity of a cistern is a function of rainfall, expected drought periods, and the rate of consumption or demand. A 50-year or a 100-year drought could be used to estimate the maximum water storage that is needed in any given area.

In general, a 90-day maximum dry period could be used to make estimates for cistern storage capacity. Using Austin as an example, a 100 gallon/day demand for 90 days would result in a 9,000 gallon requirement. Accounting for a safety factor, a 10,000 gallon storage capacity could be provided. Similar estimates could be made for other areas.

Individual small-scale rainwater catchment systems (which include the installation of cisterns), may not be economically attractive

when compared to city water supplies. However, in rural or semi-rural areas where large-scale filtered water systems are not readily available, rainwater catchment systems appear to be economically competitive with well water and associated treatment systems. Also, in large-scale turf or landscape irrigation, valuable filtered water supplies can be conserved by using harvested rainwater instead.

RAINWATER CATCHMENT SYSTEMS

Private, small-scale rainwater catchment systems in the Central Texas area range in capacity from less than 5,000 gallons to more than 30,000 gallons. The rainwater is used either for domestic purposes, irrigation, or for a combination of both domestic and outdoor use. A local nursery has a 11,500 gallon storage capacity consisting of two tanks of 1,000 and 8,000 gallons, and a 2,500 gallon pond. In neighboring counties where groundwater is of poor quality, some homeowners treat the harvested rainwater and use it for drinking.

The Environmental and Conservation Services department of the City of Austin has a very interesting co-operative program on rainwater harvesting systems with a local elementary school. The school already has a highly acclaimed 'Green classroom' program. The 800 square-foot structure is equipped with gutters and cisterns to catch water for irrigation. A drip irrigation system will feed the students' individual gardens in the back, and the ornamental landscape gardens in the front. Additionally, two other systems are planned at the school including a large cistern to irrigate a 10,000 square-foot lawn. The entire system is planned to educate the students as well as to provide the City with useful data on rainwater quantity and quality.

The National Wildflower Research Center is building a new complex near Austin which would utilize most of the roof area for

harvesting rainwater. Currently, it is planned to collect approximately 100,000 gallons of water from the roof area, for purposes such as landscape irrigation. A larger storage may be developed at a later time. The complex is expected to be completed in 1995.

The Center for Maximum Potential Building Systems in Austin is a non-profit education and research organization dedicated to sustainable design, building and appropriate technologies. It is currently in the process of constructing a 13,790 gallon on-site rainwater catchment facility. Many industries in and around Austin use large amounts of water in their routine operations. Some of the large companies are developing techniques to harvest rainwater. One such facility is estimated to be conserving approximately 20 million gallons of water per year by capturing rainwater and using it for turf and landscape irrigation.

Rainwater catchment systems not only conserve water but can also assist in the abatement of non-point source pollution. By preventing or decreasing the flow of stormwater, the systems can greatly reduce the erosive potential of the runoff water. When practised on a large scale, rainwater catchment systems can make a significant contribution in reducing non-point source pollution.

ROLE OF IRCSA-USA

Recently, the U.S. section of the International Rainwater Catchment Systems Association (IRCSA) was organized in Austin. Approximately a dozen local members have formed the core group of individuals and agencies interested in furthering the goals of IRCSA in this area. The group hopes to expand its membership and network in the next few years. IRCSA-USA plans to serve rainwater catchment enthusiasts by networking and by exchanging useful information.

IRCSA-USA holds quarterly meetings at specific locations where rainwater catchment facilities can be observed and discussed.

The first meeting in the Fall of 1994 was held at the National Wildflower Research Center, where Dr. Hari Krishna was elected President. Other office bearers elected were Dr. Allan Jones from the Texas Agricultural Experiment Station and Mr. Lawrence Doxsey from the City of Austin as Vice Presidents, and Mr. Ken Heroy from the Texas Natural Resource Conservation Commission as the Secretary. All office bearers have had international experience.

CONCLUSIONS

Although cisterns were used in Texas in the early part of this century to collect rainwater, they were largely abandoned as increased groundwater development occurred in the state. However, there has been a renewed interest recently in rainwater catchment systems, as a means of conserving and improving our natural resources.

Rainwater catchment systems appear to be economically attractive when compared to groundwater development. The recently formed IRCSA-USA group is attempting to form a network to exchange useful information amongst various individuals and agencies involved in rainwater harvesting. Rainwater catchment systems show promise in many situations where other sources of water are non-existent, or where the water systems are too expensive to develop and maintain.

RESEARCH ON THE CURRENT SITUATION AND STRATEGY FOR DEVELOPMENT OF RAINWATER USE IN JIAODONG PENINSULA

Jiang Chenguang

(Jiang Chenguang, Associate professor, Agriculture engineering department, Laiyang Agricultural college, 046 Wenhua Road, Laiyang, Shandong, P.O. 265200)

Yuan Chunqiao

(Yuan Chunqiao, Engineer, Yantai Development Corporation of Mapping Science and Technology, 30 Leshanli Road, Yantai, Shandong, P.O. 264000)

Abstract: Based on a great deal of detailed investigation data, the survey of natural geography (including geographical position, geomorphologic feature, geological survey, characteristic of water system, coastal type, climatic feature, soil type, resource distribution etc.) and the construction of forestry (including woodland area, rate of forest coverage, woodland type, woodland distribution etc.) in Jiaodong peninsula have been described in this paper. Meanwhile, the history and acquired achievement of the construction of water conservancy and the economic, ecological, social benefits brought about by utilizing rainwater resources in the past forty years in Jiaodong Peninsula have been reviewed, and the current situation of rainwater-using engineering in Jiaodong Peninsula (including engineering type, quantity and its distribution etc.) has also been introduced. Furthermore, the chief defects and drawbacks for rainwater use in Jiaodong Peninsula have been pointed out, and some factors, which must be taken into account in the project of transferring water from the Yellow River to resolve the crisis of water shortage, have been also raised. Finally, several suggestions and ideas to resolve the crisis of water shortage by fully utilizing rainwater resources have been put forward.

Key words: Jiaodong Peninsula; rainwater resources; current situation of rainwater utilization; strategy for development

I. Introduction:

Jiaodong Peninsula locates in the east of Shandong province, adjoins the Pacific Ocean, leaps over three open cities which are Qingdao, Yantai and Weihai, includes the whole cities of Yantai and Weihai, and the main part of Qingdao, has an advantageous geographical position, a lot of ports, rich marine resources and underground mineral resources, is an important area where producing temperate-zone fruits, grain and oil and an important base of marine fishery in our country, is also

one of the areas with the most developed economy.

There is a long history of rainwater utilization in Jiaodong Peninsula. In pace with the rapid development of industrial and agricultural production and the increase in population, the volume of water used rapidly increases. Freshwater crisis has become an important factor to restrict economical development. How to resolve the freshwater crisis has turned into an very important problem the local government is facing with.

II. The Survey of natural geography in Jiaodong Peninsula

Jiaodong Peninsula refers the peninsula area which is to the east of Jiaolai River, with a hilly geomorphologic type, so is named Jiaodong hilly area in geography, in which the mountains basically consist of igneous rocks, except that few mountain peaks with an elevation of above 700 meters tower over hills, the better part of the rest are undulant hilly zone with an elevation of 200 to 300 meters. Where there are gentle slopes, wide valleys, thick soil layer, three sides standing by the sea, humid climate and favorable natural condition. The whole area with a taller terrain in northeast part and southwest part (500 to 900 meters above sea level) and a lowest one in middle part (about 100 meters above sea level), in which there are mainly Laiyang basin, Taoshu basin etc. is a plain zone. The hilly edge of the peninsula is the area contacting hills and the sea. Along the coast there are small plains with a width of less than 20 kilometers, among which Peng (lai)Huang (county) Ye (county) littoral plain is the largest one, where agriculture, fishery and salt industries are all greatly developed.

The coast is zigzag in Jiaodong, from Hutou cliff in the east bank of Laizhou gulf to Qizi gulf to the south of Jiaozhou gulf is mountainous region where the land and water intersect is mostly sheer precipices and overhanging rocks, is one of the most famous base-rock harbors in our country. Along the coast, there are a lot of natural harbors. From north to south, the main harbors are Longkou harbor, Zhizi harbor, Weihai harbor, Rongcheng harbor, Sanggou harbor, Shidao harbor, Zhangjiabu harbor, Wuleidao harbor, Rushan harbor, Dingzi harbor, Laoshan harbor, Jiaozhou harbor. Most of the important harbor wharves in Shandong province including the famous Qingdao harbor, Yantai harbor, Weihai harbor, Longkou harbor, Shidao harbor etc. are in the coast. There are many islands in coastal waters which is a natural barrier of the mainland.

Among the mountain ranges in the Peninsula, Laoshan, a famous scenic spot, which is in the south of the Peninsula and about 1133 meters above sea level, is the highest. The mountain ranges in the middle and the north of the Peninsula trend towards south and turn eastward from Penglai corn, in which Daze mountain, Ai

mountain, Ya mountain, Kunlun mountain and Weide mountain are arranged from west to east. They become a watershed between the northern and southern water system. Rivers mostly rise here and flow into the sea facing north and south respectively.

Rivers in the Peninsula are short, most of them flow into the sea alone, their discharge is influenced by the weather. There are 15 rivers whose drainage area is above 300 square kilometers. Dagou river, the main source of runoff and groundwater for Qingdao city, is the first big river in Jiaodong peninsula with a drainage area of 4631.3 square kilometers and a length of 170.6 kilometers. Wulong river is the second big river in Jiaodong peninsula with a drainage area of 2652 square kilometers and a length of 124 kilometers.

The soil is brown soil in the Peninsula. Steep slopes are mostly used as woodlands and grazing lands, economic plants grow in gentle slopes.

The climate in the Peninsula belongs to monsoon climate of warm temperate zone. The annual average of air temperature is about 12 degrees centigrade, the annual average of precipitation is 720 mm and the rainfall largely concentrates in the period from July to August.

The mineral resources in Jiaodong peninsula is characterized by its variety, large reserves and wide distribution, forty-nine kinds of which have been ascertained and twenty-one kinds have been mined. Among which gold, talcum, marble, granite, magnetite and graphite are in important positions in China. There are rich aquatic resources along the coast and abundant resources of wild animals and plants on the land.

III. The survey of the forestry construction in Jiaodong peninsula

Except supplying the mankind with woods and forestry by-products, the more important effect of forest is its ecological benefit. Its benefits to environmental protection and amelioration far exceed the value of woods as well as forestry by-products itself. Forest can beautify the environment and purify air. It is subservient to people's health. Moreover, it can conserve water, protect soil, check winds and control sand, regulate the climate and reduced the natural calamities (such as wind, sand, water, drought etc.).

At present, there are about 500000 hectares of forestry lands in Jiaodong peninsula, while the practical forestry area is 400000 hectares. There are about 300 million four-side trees, 1000 million bushes, 140000 hectares of farmlands with forest net, more than 8000 kilometers roads afforested in two sides, 20% forest-covering rate and 5 million cubic meters of woods. A coastal shelterbelt network has been mainly built. In Weihai, the forest-covering rate is 34%, coastal forest-covering rate

is about 30%, hilly forest-covering rate is about 37%, so it has become an example followed by the whole country. In addition, Qingdao's Laixi was once awarded the title " Advanced County of Plain Afforestation " by Forestry Ministry of China.

There are mainly commercial forest, economic forest, shelter- forest, protecting-environment forest, scenic forest and fuel forest in Jiaodong peninsula. In addition, there are also a lot of four-side trees. The forest lands in Jiaodong peninsula are mostly distributed in mountain areas, closing-river areas and coastal areas.

IV. A historic review on the engineering construction of the rainwater utilization in Jiaodong peninsula in modern times

Irrigation works were built in a large scale in Jiaodong peninsula after the Autumn in 1959. From 1958 to 1962, 6 large-scale reservoirs with a capacity of above 100 million cubic meters, such as Chanzhi, Menlou, Muyu, Mishan, Yinfu, Longjiao mountain etc. and many hydroelectric projects with a certain scale were built. In this period, tens of reservoirs with large, middle and small-scale and other irrigation works were built, which laid a foundation for the economic development in the peninsula.

From the Winter in 1962 to the Spring in 1963, some new reservoirs were built and some were rebuilt. The conveyance systems to the areas irrigated by reservoirs were extend. Irrigated area and the area of the conservation of soil and water was enlarged.

From the Winter in 1963 to the Spring in 1964, the second irrigation works in a large scale were built. A large number of small reservoirs, dams, motor-pumped wells, wells and irrigation canals were built or rebuilt.

In 1964, hills were closed to facilitate afforestation, terraced fields and were rebuilt, some dams and reservoirs were constructed, irrigation was developed, and a comprehensive control of mountains, water, fields, forests, and roads was carried out.

From the Winter in 1964 to the spring in 1965, the construction of irrigation works in a large scale was performed for the third time, and some fields, terraced lands, reservoirs and wells were constructed, a batch of irrigation channel engineering and the conveyance systems to irrigated areas were finished.

After 1980, owing to the serious soil erosion in reservoir areas, a comprehensive control which takes a small valley as an unit was begun. By the way to combine organism, engineering and farming, a relatively integrated protection system of water and soil was preliminarily established, which conserved water, improved ecological environment, reduced flood and disaster damage. After the comprehensive control, some rare wild animals can be seen in many areas and the

ecological environment has been greatly improved. In addition, some new reservoirs were built after 1985.

From 1986 to 1989, in order to resolve the serious water shortage in Qingdao, the nation invested in a great diversion works, works of water diversion from the Yellow River to Qingdao city with a length of 290 kilometers, which transferred water from the Yellow River to Qingdao and resolved the water crisis in Qingdao.

In Jiaodong peninsula, the inland river system was harnessed mainly by taking the advantage of valleys in upper reaches to build reservoirs, conserving water to control flood and building irrigation works. By the construction in the past 40 years, great progress in rainwater utilization were achieved in Jiaodong peninsula.

Jiaodong peninsula locates in the conjuncture zone where dry monsoon meets wet monsoon, with a very clear monsoon climate. Rainfall mainly concentrates in Summer, and very small in Spring and Autumn. Drought and water-logging often occurred. In the past 10 years, the weather was abnormal, drought occurred and lasted through out the year, water resources was in a great shortage. It is the construction of water conservancy in the past forty years that has mitigated the crisis of water shortage.

Except preventing flood and removing waterlogging, the irrigation works built in the past forty years have played an important role in farmland irrigation, industrial water consumption in town and country, drinking water supply for men and livestock and ecological improvement etc.

V. The status quo and problems of rainwater utilization in Jiaodong peninsula

The water resources in Jiaodong peninsula mainly comes from atmospheric precipitation, is featured by great changes between years, uneven distribution in a year, great differences between regions, steep slopes, short rivers and speed flows. The normal average of runoff is 7410 million cubic meters, among which about 3650 million cubic meters have been exploited, which accounts for 49. 2% of the annual total amount of runoff. The storage of surface runoff is 2220 million cubic meters which accounts for 29. 9% of the total amount of runoff. Conservation of surface water was well carried out in Longkou city which was once entitled " Advanced Unit of Water conservation management ", where all the surface water were mostly used.

At present, there are about 15000 reservoirs with a whole designed storage capacity of about 3900 million cubic meters, 7000 pumping stations, 8000 motor-pumped wells, 400 dams across rivers and irrigation canals with a length of 4000 kilometers in Jiaodong peninsula.

There are 800000 hectares of effective irrigated areas, in which 660000 hectares are high and stable yield fields. Spring resources are developed, among

which the one in Laoshan was most effectively used. There are altogether 15 developed springs now. In the last more than ten years, the problem of water shortage was getting more and more serious because of the development of industrial and agricultural production as well as the lasting dry and rain deficit. In order to resolve the problem of water supply, groundwater was excessively pumped in many places. Because the groundwater could not be replenished in time, the groundwater level descended. As a result, many motor-pumped wells were out of use, some small reservoirs dried up, coastal plains were eroded more and more seriously by seawater, ground subsided, the crisis of water supply in cities was even more severe (especially in Qingdao and Yantai cities), and some difficulties were brought about to industrial and agricultural production and people's life. In addition, industrial waste water discharged from some industrial and mining enterprises polluted many rivers. Thereby, the quality of surface water descended, some water even could not be used.

Taking Qingdao as an example, water was extracted from wells before 1960, Laoshan reservoir was built in 1960, water treatment plant of Laoshan reservoir was built in 1964, from 1968 to 1977, diversion works of Dagou River was built and extended, thereby, a system of water supply composed of wells, reservoirs and runoff was gradually established. In order to save water, the ratio of industrial reused water was raised (reused ratio was 78.87%), the normal water requirement in cities was largely ensured thereby. After entering into 1980's, the crisis of water shortage occurred again. After the diversion works from the Yellow River to Qingdao city was successfully finished on October 1, 1989 and actually began to transfer water to Qingdao on November 25, 1989, the problem of water supply in Qingdao city has been resolved on the whole.

Although surface water, groundwater and water transferred from other places (to diverted water from rivers) are used together in Yantai, water supply has still been in a large shortage for many years, and its annual average shortage of water supply approximately is 100 million cubic meters. In order to reduce the water shortage in Yantai, the department concerned is researching how to transfer water from the Yellow River to Yantai city.

Although the Yellow River is one of the longest rivers in the world, its discharge is not very large. The annual average of its runoff is 36.35 billion cubic meters in the reaches of Shandong Boxing and 30.54 billion cubic meters in the reaches of Shandong Kenli, and the minimum of annual runoff in Kenli is only 9.15 billion cubic meters. When water requirement greatly increases from April till June in every year, the Yellow River is short of water, the discharge is small or even dried up. In general, the Yellow River has summer and autumn flood from July to

October with the largest water volume in August and the least in February. Seeing that the Yellow River has no large discharge, if every city which locates along its bank draws the water in large quantity, it is inevitable that there will be no water to be transferred in the future. So, it is not a long-term plan to resolve the problem of water shortage only by transferring water from the Yellow River. Making a full use of rainwater resources is the last and effective way to completely resolve the problem of water shortage.

VI. A few suggestions on full use of rainwater resources to resolve crisis of water shortage

1. Controlling river channels conscientiously, strengthening the work of dredging river channels, widening river surface, heightening dikes and promoting the capacity of flood-discharge.

2. Establishing dam sluices in different levels in the same river course, building necessary diversion works, increasing water storage and raising rainwater use efficiency. A dam sluice has two functions of retaining water (it is the main function) and discharging flood. It should be designed according to the largest flood volume in a certain stage.

3. Setting up shelter-forests on both sides of all river courses (including the small tributary). Shelter-forest belts should be wide so that they can conserve water, protect dikes and regulate climate. The construction of shelter-forests for the protection of water sources, the smallest width of a forest belt and the protection of shelter-forests should be provided by law.

4. Strengthening the supervision and management of waste water discharge which comes from industrial and mining enterprises, taking drastic measures to prohibit all waste water which will possibly cause river pollution from being drained into ditches and rivers without any treatment with natural running water, to ensure the quality of rainwater storage.

5. Confining the exploitation of groundwater strictly. Without special demands, the water requirement for industry and living should be supplied by surface water.

6. Strengthening forestry construction, planting trees in all the barren mountains and lands which are suitable for woods, increasing the rate of forest coverage, thus to increase the volume of water storage and improve the ecological environment. Increasing four-side tree planting, net farmlands with woods and comprehensively control of mountains, water, lands, forests and roads.

7. Completely changing the form that rainwater and sewage flow together when designing water supply and drainage of a city, discharging rainwater and

sewage separately, and retrieving rainwater by a suitable measure, thus greatly decreasing the pressure of sewage treatment plants.

8. Building more reservoirs and dams in appropriate places to increase the volume of retained surface water.

9. Carrying out comprehensive development in reservoir regions. Planting trees and grasses around the sources of reservoir areas so as to increase the reservoir's capacity of water storage. Strengthening the inspection on dam body in reservoir areas to ensure the reservoir's safety. Building more small hydropower stations in suitable places because a small hydropower station is a power plant without any pollution. Developing suitable freshwater aquaculture and tourist trade in reservoir areas to increase the economic benefit.

10. Developing water-saving agriculture, widely popularizing the water-saving irrigation technique to reduce the agricultural water requirement.

11. Closing hillsides to facilitate afforestation, increasing the rate of vegetation coverage, protecting wild animals and plants, and ameliorating the ecological environment.

12. Strengthening the construction of legal system, the propagation, education and the spread of popular science, increasing people's sense of ecological environment and water saving.

We firmly believe that by the joint efforts of mankind, the rainwater resources will be used more rationally and fully, the crisis of regional water shortage will be completely resolved, and an earth with more beautiful environment will reappear in the future.

AN OVERLOOK TO THE DEVELOPMENT AND USE OF RAINWATER HARVESTING SYSTEMS IN IRAN

*

JAMAL GHODDOUSI

ABSTRACT

On study areas on the north-east and north-west part of Iran (Khorasan and Azarbaijan provinces), there are various types of rainwater collection, harvesting and utilization systems. The use of these systems turns back to 2500 years ago, whilst there are also some newly developed systems.

The study areas are located in the Mediterranean Semi - Arid regions, where summer months are dry, and if there is precipitation, the intensity and frequency of rainfall is spasmodic and irregular. Because of this climatical condition dwellers of these regions have well understood how to overcome the problem through the use of different methods of collecting and storing rainwater and its utilization.

The aim of this paper is to introduce general description of the most important rainwater harvesting and storage systems. Furthermore, some related technical points of each system is also discussed.

INTRODUCTION

In Iran, the use of water harvesting methods turns back to 2500 years ago. Collection and concentration of subsurface flow by excavation of long infiltration galleries or Qanat (Kanat), is the most surprising of ancient water harvesting methods. According to Davis and DeWiest (1966), Kanats were used first about 2500 years ago in Iran. This method together with some others are still in use in Iran. Hudson (1987), states that there are 40'000 Kanats in Iran, supplying 35 percent of the water supplies of the country. He also notes that much of Kanats are in areas with mean annual rainfall of 150-250 millimeters.

The use of runoff from roofs and surface runoff from ground catchments and storing collected water into the underground cisterns was another common technique for securing water supply in the arid and semi - arid regions of Iran. Although this method of rainwater or water harvesting

* Research Scientist; Soil Conservation & Watershed Management Research Center, P.O. Box 13445-1136, Tehran, Iran

techniques is still in use in some of cities, towns and villages, it is not used as much as the former times. There are however, many remains of underground cisterns in the urban areas located around the old trade routes as well as old cities (Koocheki 1992), indicating that this method has widely used for providing water in different climatic condition of the country. Presence of old - ago farm ponds, dams, runoff irrigated farms are some other examples of the use of water harvesting technique showing that Iranians have had lots of knowledges on application of water harvesting and it's use and benefits as well.

The results of the recent studies in Iran show that there are three main reasons for decrease in use of ancient water supply as follows:

- a) Widespread introduction of diesel-engined pumps and electric motors all over the country.
- b) Concentrated water supply systems through the use of groundwater resources.
- c) Construction of big dams.

A part from the above reasons, more recently interest in revival of traditional water harvesting techniques as well as modern methods is increased. As a consequence, extensive research projects were conducted and some new projects are also undertaking. Furthermore, wide variety of newly developed methods applied all over the country.

To summarize, it is believed that the use of water harvesting techniques is essential for overcoming the constraints and problems arising from shortage of water particularly, in the deserts and steppes of Iran. It is also believed that optimization of available rainfall and surface water can be better done by development and extension of simple and adapted water harvesting techniques not only for providing water for domestic, livestock and agriculture purposes, but also for artificial recharge of groundwater, soil erosion control, forests and rangelands rehabilitation, as well as restoration of environment resources.

IMPORTANCE OF WATER HARVESTING IN THE ARID AND SEMI-ARID REGIONS OF IRAN

In the Mediterranean arid and semi-arid regions of Iran, summer months are usually dry and if there is precipitation, the intensity and frequency of rainfall is spasmodic and irregular. Clearly, under this climatic condition water is the most limiting factor for restoration of environment resources, plant production and socio-economic development. Since the arid and semi-arid regions constitute about 90 percent of total geographical area of Iran, these regions actually have important role on economic deve-

lopment of the country.

However, according to Pabot (1967) there are three major climatic zones in Iran:

a) Caspian Climatic Zone; this climate compares with Mediterranean climate and because of uniformly distributed precipitation through out the year, there is not shortage of water. Thus ample water, together with good alluvial soils, make the area the richest agriculture area of Iran. Under this climatic condition particularly in the east part of the area, use of collected rainwater directly from roofs is common way of supplying water for drinking in villages.

b) Baluchi Climate Zone; in the south-east part of Iran, the climate is strongly influenced by the Persian Gulf. Since annual precipitation in this zone varies from 70 to 200 millimeters and it's distribution is uneven, there is always shortage of water. Furthermore, restriction of precipitation for 4 to 6 months together with low number of rainfall events are the main cause for aridity of the areas. Under this climatic condition, summers are extremely hot with no rainfall. Thus agriculture is mainly depended on irrigation. Persence of runoff irrigated farms and some other small scale traditional water harvesting systems which are in use yet in some of villages, indicate that even under this harsh climatic condition, floodwater harvesting offers its greatest advantages.

c) Irano-Turian Climatic Zone; central and eastern plateau of Iran occupy more than one-half of the country (Dewan and Famouri 1964). The climate of this regions of Iran is continental, temperate and arid. Annual precipitation, which is related to elevation (2'500 meters from sea level in the north to 500 meter in the south) varies from about 400 millimeters per year in the north to less than 100 millimeters in the central and southern parts. Although aridity is a characteristic of vast areas of Irano - Turian Climatic Zone, there are also semi - arid regions in the Elburz Mountains and in the Zagros Mountains in the northern and in the western parts of the country respectively. Annual precipitation in the semi- arid regions varies from about 300 to over 600 millimeters. In these regions precipitation is confined to the late fall, winter and early spring months, thus summer months are usually dry and if there is precipitation, the intensity and frequency of rainfall is spasmodic and irregular. Here again there are some places where water is in short-supply. However, since under Irano-Turian Climatic Zone substantial amount of food and feed of the country are produce, needs for water is increasing. On the other hand, considerable amount of food and feed production in this Climatic Zone are produce by rainfed agriculture

(i.e. dry farming). According to Brunis (1986), rainfed agriculture can not be feasible without the use of water harvesting techniques in areas where there is low number of rainfall events. Since similar condition do exist in most parts of Irano-Turian Climatic Zone (especially, where annual precipitation is about 200 to 400 millimeters) rainfed agriculture is not feasible. Therefore, local people have been and still are being awared of the effect of application of water harvesting techniques in decreasing the risk of crop production as well as increasing water supply for multi-use purposes. In this regard, evidences such as age-old underground cisterns, kanats, farm ponds, runoff irrigated farms are some obvious examples.

However, as the arid and semi-arid regions of Iran occupy 824'000 and 659'200 square kilometers (km2) of the total land area of the country (1'650'000 km2 is the total land area of Iran) respectively, therefore there is increasing interest in development of these regions. But in most parts, water being the most limiting factor for development of the arid and semid-arid region, is also main cause of sever soil erosion. Indeed, because of loss of proper land cover large proportion of precipitation appears as surface runoff in form of spate flows or flash floods in fall or spring seasons. To overcome these problems, the best and rational way seems to be the use of different small scale of water harvesting techniques particularly, the most simple and economical one . In order to achieve this point, it is recognized that traditional water harvesting techniques must be revived and completed and modern techniques have to be adapted, and applied extensively in much of the arid and semi- arid regions of the country.

TERMINOLOGY AND DEFINITION OF WATER HARVESTING IN SUMMERY

Water harvesting is a term which first introduced by Geddes in 1963 in Australia (Pacey with Gullis 1986). Although this term is purely hydro-agronomi term as it defined by Geddes, it also has hydrological meaning when is used to describe methods for controlling runoff water from various sources for various purposes. This is perhaps because of the great potential of water harvesting in providing water as well as water conservation, flood and soil erosion control, etc.

However, according to Myers (1975), and pacey with cullis (1986), water harvesting has defined by Geddes as " the collection and storage of any form of water for irrigation uses ". Later on, wide variety of terms and definitions have introduced for water harvesting, so that many outhors of books and articted on water harvesting, introduce specific definition to

their own purposes. Evenari and Nessler (1986), state that the term water harvesting does neither restrict to specific kind of runoff, nor to specific purposes. It seems however that there were not so much attempts in introducing strict definitions that could describe all related aspect of water harvesting.

Clearly, it seems that based on the various forms of runoff from various source and for various purposes, specific definitions do exist and still some more may be introduced. For example, pacey with Gullis (1986), by restricting rainwater harvesting to " water running off surfaces on which rain has directly fallen " introduce a specific definition for water harvesting. Hudson (1987), introduces almost the same definition for water conservation. In some of other definitions for water harvesting, runoff from whatever type of catchment or ephemeral stream (Bruins et al. 1986), local surface runoff (Boers and Ben-Asher 1982), and valley floodwater (Shanan and Tadmor 1979) are included, but in all definitions however, the use of water from perennial rivers are excluded.

Apart from all the above definitions of water harvesting, it is very important to keep in mind that while collection, storage and utilization of precipitation and resultant runoff are inevitable and integral parts of water harvesting systems, but as Boers and Ben-Asher (1982), emphasize they do not include large-scale water harvesting from relatively big watersheds in terms of storing river water in large reservoirs as well as exploiting of relatively deep groundwater. Therefore for purposes of this paper, the term water harvesting is used to describe different small-scale water harvesting systems methods and techniques aimed at collecting or concentrating and storing of available precipitation in form of snow and rain and resultant runoff in forms of rooftop runoff, overland flow, stream flow and subsurface flow for various purposes (domestic, agriculture , livestock and other purposes).

DESCRIPTION OF THE STUDY AREAS

The study areas are situated in north - west and north - east parts of Iran respectively. East Azarbaijan province is one of the mountainous regions of the country. The climate of this study area is continental and semi-arid. Precipitation which amounts to 250-900 millimeters per year is confined to the late fall, winter and early spring. Summer temperatures in the low lands of this province are relatively high and in the upland are mild while winter months are cold with good snow cover particularly at the higher elevations. In this study areas high intensity rainfalls are frequent,

especially in autumn and spring months. Since the mountainous and hilly regions make up about 75 percent of the total area of this province, intensive irrigated agriculture in vast areas has not and still is not being possible. Thus rainfed farming is the common type of farming. Furthermore, because of climatic condition together with improper land use (i.e. faulty agriculture, overgrazing, tree cut, etc.) large proportion of precipitation appears as spate flows or flash floods.

Khorasan province is a largest province in Iran. This province consists of mountainous and hilly areas in the north and plain areas in the south. The plain areas of Khorasan consists itself of high plateau, broken by small mountain ranges where salt flats are common in the depressions. In this part of Khorasan aridity is a characteristic with summers being temperate to hot and dry. Winter climate is determined by precipitation which is limited and erratic. Annual precipitation ranges from 300-600 millimeters in the north to about 100-250 millimeters in the south of this province. Although precipitation is confined to the winter and autumn in the mountainous part of Khorasan, but because of good snow cover at the higher elevation, there are lost of springs and good natural recharge of groundwater. In the southern part, low amount of precipitation which is characterized by high intensity, low rainfall events with short duration together with frequent wind tend to sever aridity and shortage of water. Therefore, because of harsh climatic condition and sparse vegetal cover aridity is a common feature of the environment. It is in this part of study area that the most extensive dune field is located. In this province, the use of both traditional and modern water harvesting techniques is also very usual. It is in southern part of this province that rainwater collection offers its greatest technical advantage in terms of the sand dune stabilization and conservation of the scarce water resources.

TRADITIONS IN WATER HARVESTING

In the study areas, several traditional methods of harvesting water from various sources have identified which have been and some extent are being used for domestic, livestock and crops. However, traditional water harvesting systems in the study areas refer to activities related to water exploitation from surface and sub - surface water and in particular cases from shallow groundwater tables for various purposes. The most common systems are as follows:

a) Long Information Galleries;

Collection of water from alluvial fan deposits and soft sedimentary

rock by constructing a complex system of vertical dug wells and sloping long information galleries, is an ancient water harvesting system in the study areas. These complex structures are commonly several kilometers long, collect water for both agricultural and municipal purposes. This technique is called "Qanat" in Khorasan province as well as most part of the country and "Karez" in East-Azerbaijan. It is important to note that still about 25 percent of the water supplies of the study areas mainly where mean annual precipitation is 150 - 200 millimeters are supplied by the use of this technique. In Khorasan when water from qanat is intended for domestic use especially for drinking, water first is directed into the public and private underground cistern to avoid pollution as well as improving water quality in particular cases.

Since many of qanat and Karez systems in the study areas have dried up due to the over exploitation of groundwater resources, it is believed that this system has to be combined with techniques of surface water harvesting in order to artificially recharge of shallow groundwater tables. Furthermore, in order to exploitation of shallow groundwater, drilling small bores (Max. 50 mm) radially and horizontally in sedimentary rock to supply small quantities of water for watering stock, is another common type of sub-surface water harvesting technique in the study areas. This technique which is called "Chah-E-Ofoghi" mainly is used in mountainous areas not only for providing water, also for developing existing springs.

b) Farm Ponds (Gol and Bandsar):

These are actually typical form of water harvesting which are used in study areas. In Khorasan, "Bandsar" is called to a structure which is constructed by small earthen walls in flat or hilly lands and in particular cases in small gullies. The rain and storm water running off upper or neighbouring catchments is collected and directed to these small reservoirs. Height of earthen walls or bunds usually do not exceed 3 meters and because of high evaporation rate, collected water always can not be used for irrigation of lands. Therefore, the main purpose of this system is to trap surface runoff for increasing the amount of water stored in the soil profile. Use of this system in arid regions of Khorasan is very common and tends to decrease the risk of crops failure.

Almost the same system is used in East - Azerbaijan. In this area the structure which is called "Gol", is constructed mainly for supplementary irrigation purpose as well as artificial recharge of Karez and existing springs. Here again, height of earthen wall(s) varies from 1-3 meters depending on the feature of the landscape. Since this system is built near the

farm lands, so that stored water can easily be distributed on the farms, the surface runoff from various sources usually is diverted to the ponds. In cases when this system is used for artificial recharge of Kareze and springs, the height of earthen wall(s) some times increase to more than 3 meters. In the arid regions of East Azarbaijan where water is collected and stored from rainwater or snow melt water, it can only be used for supplementary irrigation in the beginning of growing season. However, this technique is used for artificial recharge of qanats or Kareze systems in hilly lands where there are alluvial fan deposits.

c) Underground Cisterns (Abanbars):

Abanbar which is also called "Hoze" in south of Khorasan province, is used for storing collected water from various sources especially rainwater for domestic use. Abanbar is actually underground cistern which is built in different types. This system has two main sections. Storage bag mostly in shape of cylindric, covered by stones or bricks ceiling is the biggest section of the system. Catchment area is the second section which usually is prepared by making dikes around the storage bag, so that all of the rainwater can be collected and directed into the cistern. There are several types of this system in the study areas. In some cases when amount of available water for direct harvesting of water from roof surface runoff or ground catchments is not adequate for storing required water for long period, water from existing seasonal rivers, springs or qanats is also directed into the underground cisterns. This system has been and still are being used in areas where there is relatively great need for drinking water.

d) Contour Furrows (Contour Bunds) and Contour Banks:

Contour furrows are built without a longitudinal gradient for collecting surface runoff from the catchment to increase soil moisture on the rangelands as well as on the cropped area. This rainwater harvesting technique offers its greatest advantage on soil with high infiltration rate. Therefore, on heavy soils, contour furrowing usually can be less effective only because of the lower infiltration. In East Azarbaijan however, this technique is widely used on gentle slopes up to 12 percent where mean annual precipitation varies from 200-300 millimeters. It is found that with a catchment ratio of 2:1; wheat and barley were successfully grown only with 200-300 millimeters of rainfall. The most important point in laying out of contour furrows is that, they must be precisely constructed on the contours. Otherwise, there may be a danger of uneven depths of ponding behind the banks. In Khorasan province, this technique is used for trapping surface run-

off in desert areas for rangelands rehabilitation as well as preventing and combating desertification. Since there are several types of contour bunds, it is found that on steep slopes the use of "Gradoni", and "Contour Banks" offer better advantages. These techniques of harvesting rainwater can be used on slope land, varying from 30 to 70 percent. Two types of these techniques were tested in study areas in form of long and short structures. Long gradoni and contour banks are built with more than 6 meters long and short one no more than 3 - 6 meters. It should be noted that the objectives of using this techniques are as follows:

- To trap or hold rainwater where it falls in order to store collected water in the soil for tree or tree crops and plant use.
- To prevent flash floods as well as erosion control on slopes where plant cover has deteriorated due to the mis-use environmental resources.

However, in study areas the following formula is used for determination of vertical spacing between either gradoni or contour banks

$$H/P = \frac{2}{i} \cdot 150 \quad (1)$$

Where

H = the vertical distance between terraces.

P = the slope percentage.

i = the intensity of rainfall equal to 3 millimeters per minutes.

i' = the maximum intensity of rainfall at the site in millimeters per minutes.

The horizontal distance in meters can be determined by the following formula: $L = H/P$

e) Runoff Farming and Water Spreading

Since the climate of study areas is Mediterranean climate, the precipitation mainly is confined to late fall, winter and early spring. Therefore, because of high intensity of rainfall in fall ^{and} spring times particularly, in early spring when rain falls over the snow and tends to rapid melting of snow on uplands, there are always sudden floods in lowlands. Since this condition do exist in study areas, people traditionally have been and still are being used floodwater for various purposes mainly for floodwater farming and artificial recharge of groundwater. Although there are wide variety of runoff and floodwater farming in both study areas, two different methods are very common. The first method is based on diverting runoff from stream by constructing diversion structures such as small dams or rock filled barrages and directing water onto terraced alluvial outwash fans

which are called "Dasht". The second method is based on direct harvesting of spate flows from small creeks and gullies and spreading it onto terraced fans in down streams. In this method earth bunds are used as collection arms where there is no creeks or gullies in order to collect surface water from upper catchment area.

However, in both methods or systems runoff from wild land watersheds is carried to the terraces. More recently because of rapid decline of groundwater, tables interest in use of traditional techniques of runoff and flood-water farming were increased. In order to get better advantages some modifications were made. The modifications were mainly on design and determination of vertical spacing of terraces as well as surveying and construction procedure, so that the systems can offer their benefits not only for plant production, but also for artificial recharge of groundwater tables as well.

CONCLUSIONS AND RECOMMENDATIONS

In areas with limited rainfall in a hot summer season, storing more water in the soil profil appears to be workable strategy for overcoming the scarcity of water. In the arid and semi - arid regions of Iran although construction of large dams and drilling deep wells are inescapable for providing water for large concentrations of population in big cities and towns as well as intensive irrigated agriculture, it must be bore in mind that even these water supply systems are facing with sever problems such as rapid siltation of reservoirs and rapid decline of groundwater tables. Considering the advantages of water harvesting techniques in providing water for various purposes, flood and erosion control, artificial recharge of groundwater and finally its great influences in restoration and rehabilitation of environmental resources, it seems that in addition to revival of traditional water harvesting systems, completion of age - old systems and modification of them and using new devices, extension of the use of water harvesting techniques and training programs particularly for farmers and people who are living in rural areas in national scales are essential and imprative for sound water management. There is also great need for strict definition of water harvesting in different climatical conditions.

REFERENCES

- Boers, T.M.; and Ben-Asher, J. 1982. A review of rainwater harvesting. In: Agricultural Water Management 5: 145-158.
- Brunis, H.J.; Evenari, M.; and Nessler, V. 1986. Rainwater harvesting agricul-

- ture for food production in arid zones: the challenge of the African famine. In: *Applied Geomorphology* 6(1): 13-33.
- Davis, S.N.; and DeWiest, R.J.M. 1966. *Hydrogeology*. New York. London. Sydney. John Wiley and Sones, Inc.
- Dewan, M.L.; and Famouri, J. 1964. *The soils of Iran*. FAO pub. Rome, Italy.
- Gil, N. 1985. *Watershed management: with special reference to soil and water conservation*. FAO, Soil Bulletin 44. Rome, Italy.
- Hudson, N.W. 1987. *Soil and water conservation in semi-arid areas*. FAO, Soil Bulletin 57. Rome, Italy.
- Koocheki, A. 1992. Water harvesting practices in north-east Iran: An overview. *Proceedings of the 5th International Conference on Rain Water Cistern Systems*. February, 1992: 784-787.
- Myers, L.E. 1975. *Water harvesting and management for food and fiber production in the semi-arid tropics*. ARS/USDA, Berkeley, USA.
- Pabot, H. 1967. *Pasture development and range improvement through botanical and ecological studies*. Report to the Government of Iran. FAO, Project No. TA.2311. FAO, Rome, Italy.
- Pacey, A.; with Cullis, A. 1986. *Rainwater harvesting: The collection of rainfall and runoff in rural areas*. II publication. London, UK.
- Shanan, L.; and Tadmor, N.H. 1979. *Micro-catchment systems for arid zone development: a handbook for design and construction*. Hebrew University. Jerusalem.

RAINFALL UTILISATION IN THE ISLANDS OF HAIZHOU BAY

Liang Haitang¹

Abstract: There are 14 rocky islands, scattered in Haizhou Bay and its adjacent sea, off Lianyungang City in Jiangsu Province, P.R.China, ranging from 34°31'-35°08'N, 119°16'-119°55'E. There are no rivers in the islands because of their small area and precipitous landform. The major supply of fresh water to the islands consists of 1. piped water from land, 2. rainfall utilisation and 3. water transported by ship. Rainfall utilisation makes a remarkable contribution to water supply to the islands. There are 3 forms of rainfall utilisation, i.e. 1. damming rainfall in reservoirs, 2. drawing ground water and 3. decentralised collection of rainfall. In Dongxiliandao Island about 140,000 m³ of mean annual runoff have been dammed in 3 reservoirs, which have a total capacity of about 100,000 m³, and supply sweet water to about 3500 local residents. In addition, about 100 m³/d of ground water from 12 wells and 3 springs are obtainable in summer in the island. In Qinsandao Island 30 m³/d of ground water from a well is the sole source of sweet water to about 300 local fishermen. Water from decentralised collection, low in hygienic quality, is used mainly for washing, feeding livestock, or irrigating cultivated land.

1. Background information

There are 14 rocky islands, scattered in Haizhou Bay and its adjacent sea, off Lianyungang City of Jiangsu Province, P.R.China, in an area ranging from 34°31'-35°08'N, 119°16'-119°55'E. The biggest one is Dongxiliandao Island with a land area of 5.4153 km², and the smallest one Xiaoqushan Island with a land area of less than 500 m² (Table 1). Except Yangshandao Island, which became an artificial tombolo since a causeway was built between it and the land, the nearest island is Dongxiliandao Island, 2 km off coast, and the farthest one, Pingdao Island, 65 km away from coast. Most of small islands remain desertified and barren. Human activities exist in some of the islands close to mainland. There are permanent dwellers and fishing villages in Yangshandao Island and Dongxiliandao Island, which are in an initial stage of development with their industry concentrated in fishery. In 1990 the inhabitants in Dongxiliandao Island reached 5010, and its 8 small factories generated about a 200 million Yuan of turnover. Construction of a causeway to Lianyungang Harbour is complete and new harbour development is planned along the causeway. While in the nearer and smaller islands, such as

¹Associate researcher at Nanjing Institute of Geography & Limnology, Academia Sinica, 73 East Beijing Road, Nanjing 210008, P.R.China

Qinshandao Island, Kaishandao Island and Cheniushandao Island, there are simple shelters for fishermen who go there seasonally for fishing. In Qinshandao Island, for example, seasonal dwellers totalled about 300 in recent years.

The major supply of fresh water to the islands consists of:

1. Piped water from the mainland
2. Rainfall utilisation
3. Water transported by ship.

Piped water is supplied to Yangshandao Island and the lower western part of Dongxiliandao Island which are both close to land, densely populated and lack suitable geological and landform condition to hold ground water or catch runoff. Qinshandao Island and most of Dongxiliandao Island rely on rainfall utilisation. Water is occasionally transported on ships, by fishermen themselves, to those small and uninhabited islands when they need it there.

Table 1 Location and area of islands of Haizhou Bay

name of island	Latitude	longitude	area (km ²)
Dongxiliandao	34°45'24"	119°28'02"	5.4153*
Yangshandao	34°41'58"	119°29'53"	0.1545*
Qinshandao	34°52'07"	119°18'33"	0.1496*
Bingdao	35°08'24"	119°54'30"	0.1361*
Zhudao	34°46'20"	119°20'31"	0.1074*
Dashandao	35°00'30"	119°53'25"	0.1093*
Cheniushandao	34°59'42"	119°49'18"	0.0551*
Kaishandao	34°31'47"	119°52'15"	0.0128*
Gedao	34°45'25"	119°22'39"	0.0116*
Pingdaodongjiao	35°08'29"	119°55'10"	0.0018**
Niujiaodao	34°59'10"	119°48'21"	0.0013**
Niuweidao	34°59'25"	119°49'11"	0.0026**
Niubeidao	34°59'10"	119°48'40"	0.0057**
Xiaogushan	34°46'45"	119°26'52"	0.0012**

*. Land area above sea level.

**.. Total area, including inter-tidal area.

2. The water resource of the islands

The average annual precipitation on these islands ranges from 782.1 mm (in Dashandao Island) to 878.2 mm (in Dongxiliandao Island), more in islands close to land and less in those far off. Large annual variability and uneven monthly distribution are characteristic of precipitation on the islands. In Dongxiliandao Island, for example, the annual precipitation totalled 1253.5 mm in 1990, but only 520.7 mm in 1988. Most of rainfall precipitates in the summer. Statistics show that precipitation in the months from June to September, amounts to 69.2% of the annual total, while in winter, from December to February, it was only 5.1%.

Since the islands have a small land area, and are precipitous in landform, there are no rivers. Among the 14 islands, five have a land area less than 500 m², eight from 0.01 to 0.15 km². Only one island, Dongxiliandao Island, has a land area over 5 km², 70% of which is steeper than 20°. Under such landform conditions runoff is bound to flow rapidly into the sea. Furthermore thin soil and sparse vegetation increases the runoff. The runoff coefficient is as high as 70 in the islands, while the infiltration coefficient is about 0.10-0.12. Being fed only with rainfall, the water table and capacity of ground water changes sharply with season and rainfall intensity. In the summer the water table is higher and capacity is bigger than in other seasons. Some springs appear because ground water spills over ground in the season. Most of ground water is lost to the sea, and a small part of it is consumed by locals. The ground water appears in 3 forms, i.e. pore water, crevice water and crevice-karst water. The degree of mineralization and hardness of ground water is larger in pore water than in crevice water (Table 2).

Table 2 Basic data of ground water in the islands of Haizhou Bay

No.	stored in	water type	gross hardness (mg/l)	mine. degree (g/l)	pH
1	crevice-cave	Cl-Na.Ca	283.65	-	6.8
2	crevice	Cl.SO ⁴ -Na.Ca	63.72	0.15	8.0
3	pore	HCO ³ .Cl-Ca.Na	292.17	0.64	8.0
4	crevice	Cl.SO ⁴ -Na.Ca	58.93	0.14	8.0
5	pore	Cl-Na	107.57	0.32	8.0
6	crevice	-	-	-	-
7	crevice	-	-	-	-
8	pore	Cl-Na.Ca	174.13	0.41	7.3
9	crevice	Cl.HCO ³ -Ca.Na	78.63	0.18	8.0
10	crevice	-	-	-	-
11	crevice	-	-	-	-
12	crevice	Cl-Na	68.69	0.20	6.0
13	crevice	-	-	-	-

Source: Comprehensive survey of island resources of Jiangsu Province.

3. Current rainfall utilization in the islands

There are 3 forms of rainfall utilization in the islands :

- 1.Damming rainfall in reservoirs
- 2.Drawing ground water
- 3.Decentralized collection of rainfall.

On the southern slope of Dongxiliandao Island 140,000 m³ of runoff have been dammed in 3 reservoirs, with a total catchment area of 0.23 km², total capacity of 100,000 m³, which supply fresh water to about 3500 local residents (Table 3). On the southern slope of Dongxiliandao Island residential quarters have been distributed up to 100 m above sea level, which created a limitation on the location of dams for reservoirs and has reduced the storage capacity. The whole of the suitable catchment area has not been fully used for rainfall collection. The catchment area of the three reservoirs amounts only 4.25% of total land area of the island, dammed up runoff only 2.94% of average annual precipitation. There are three other valleys on the northern slope of the island, which have a

total catchment area of 0.38 km². These 3 pieces of land have not been used for rainfall collection since there are few residential houses there. Along with the construction of the causeway between the island and the nearby Lianyungang Harbour, the land on the northern slope of the island will be soon reclaimed. A overall land use plan is necessary in order to avoid placing other construction in the valleys, and to fully use the landform for rainfall collection.

Table 3 Basic data of 3 reservoirs in Dongxiliandao Island

No.	catchment area (km ²)	runoff (m ³)	capacity (m ³)	consumer
1	0.05	30,000	25,000	1300
2	0.13	80,000	50,000	1300
3	0.05	30,000	25,000	900
total	0.23	140,000	100,000	3500

Ground water in the islands is tapped from wells and springs. Exploitation of ground water exists in Qinshandao Island and Dongxiliandao Island. The ground water in Qinshandao Island, appearing in crevice-karst water, is the sole water supply to about 300 fishermen, who live there seasonally for fishing. Water is extracted from a well, 18.65 m in depth with the water table 12.45 m under ground in the summer. The estimated daily capacity of the well was 30 m³. In Dongxiliandao Island ground water has been extracted from 12 wells and 3 springs. The depth of each well ranges from 1.32 m to 10 m, water table from 0.8 m to 7.9 m, daily capacity from 3 m³ to 20 m³ (Table 4). The water volume from springs changes sharply with season. In a drought season they might dry up, in the winter daily capacity might be about 5 m³, while in the summer over 15 m³. It has been estimated that the obtainable ground water of this land in summer could be over 100 m³ per day, which serves as an important supplementary fresh water resource

Table 4 Basic data of wells in the islands of Haizhou Bay

No.	location*	depth (m)	table** (m)	capacity (m ³ /d)
1	Q	18.65	12.45	30.0
2	D	-	0.80	3.0
3	D	5.00	3.00	10.0
4	D	10.00	4.20	-
5	D	1.32	0.88	20.0
6	D	4.50	3.60	-
7	D	9.50	4.00	-
8	D	6.65	3.78	10.0
9	D	3.30	2.97	20.0
10	D	8.40	7.90	-
11	D	4.00	3.00	-
12	D	3.30	2.70	<5.0
13	D	4.00	3.00	-

*. Q-Qinshandao Island, D-Dongxiliandao Island

**in metres under ground

source: Comprehensive survey of island resources of Jiangsu Province.

The installation of a decentralized rainfall collection system, which has simple techniques and variable forms, is widely distributed around settlements. The water collected in this way, being low in hygienic quality, is usually used for washing, feeding livestock, or irrigating cultivated patches.

4. Proposals for rainfall utilization in the islands

The deficiency in the fresh water supply is one of the impediments to the development of the islands. The problem will be particularly acute when a transformation takes place in living and working patterns in the near future due to causeway and harbour construction. On the other hand the economic and ecological significance of rainfall utilization has not been recognized by local policy maker, which has led to rainfall utilization in the islands being unplanned and rainfall resource wasted.

In a scheme for water supply to the island the following proposals should be taken into account:

1. To recognize the significance of rainfall utilization in the islands
2. To tap thoroughly the potential of rainfall utilization in order to fully use this resource and to maintain environment quality
3. To improve installation for rainfall collection in order to guarantee water quality.

5. Conclusions

This brief paper is based upon preliminary research over the years from 1990 to 1992 and is part of a comprehensive survey of the island regions of Jiangsu Province. It is hoped that when funds and resources are available further research will be carried out.

DEVELOPMENTS IN RAINWATER CATCHMENT SYSTEMS IN EASTERN AND SOUTHERN AFRICA

John Gould¹

ABSTRACT

Despite some progress in recent years, more than 70% of rural dwellers in sub-saharan Africa still lack access to improved water supplies. Even in urban areas 20% of the population still depend on unimproved sources. In recent decades a number of developments have taken place in rainwater catchment systems technology and implementation strategies in several parts of Africa which could have a major bearing on how improved water is supplied to some of the hundreds of millions of people still unserved. The spread of corrugated iron roofing material in place of traditional thatched roofs has enabled the development of roof catchment systems based on a variety of innovative tank designs. Rainwater collection from ground, rock and pan surfaces has also been developed in several parts of Africa. Several of these key developments from eastern and southern Africa are examined and their success to date and future potential assessed. Particular attention is focused on projects from Kenya, Botswana and Namibia and a number of innovative designs and approaches are presented.

INTRODUCTION

The direct collection of rainwater especially from roofs is becoming increasingly widespread throughout many parts of Africa. This paper focuses particularly on the developments in rural eastern and southern Africa where rainwater catchment technology is widely used. Rainwater is also collected as a supplementary source in many urban and peri-urban areas. Considerable potential exists for increasing urban rainwater collection as proposed for Nairobi by Ladu (1993) and for Gaborone, Botswana by Gurusamy and Gould (1993).

In rural areas the rapid transition from predominantly grass thatched to corrugated iron roofing during the last two decades has provided people with the opportunity to collect roof runoff more effectively. Indeed, it seems clear that in many areas part of the reason for the preference for corrugated iron roofing material over thatch is its utility for rainwater collection. The collection of rainwater in rural areas is, however, by no means ubiquitous. It tends to occur particularly in regions where alternative water sources are either unavailable or not yet developed. Since in most of rural Africa people, especially women and children, have to walk at least some distance to collect water (even where reticulated stand post supplies are available) the advantages of collecting and storing rainwater at the point of

¹ Lecturer, Dept. of Environmental Science, University of Botswana,
P/Bag 0022, Gaborone, Botswana Fax: +267-305425
Secretary-General, International Rainwater Catchment Systems Association

consumption are obvious. In areas where water sources are remote and in the dry season or drought periods it is not uncommon for people to walk anything from 1 - 10 km to collect water, the advantages of being able to collect any rainwater therefore are very considerable. Every 20 litres collected is 20 litres less to carry.

CLIMATIC CONDITIONS AND RURAL WATER SOURCES

While it is difficult to generalize about climatic conditions over such a large region where mean rainfall varies from <5 mm/a to >3000 mm/a, a few relevant points can be made. Over most of eastern and southern Africa rainfall tends to be seasonal with distinct wet and dry seasons. The dry season usually lasts anything from 3 to 9 months - it tends to be longer in the drier areas where recurring droughts are also more likely and may last for several years. Some areas particularly in East Africa experience two distinct wet seasons (short and long rains). Most people live in areas receiving mean annual rainfall of between 300 mm - 3000 mm and mean evaporation rates of between 1500 mm - 3500 mm per year.

Water sources in rural areas in much of Africa comprise a mixture of traditional sources (hand-dug wells, rivers, ponds, springs, haffirs, etc) and improved sources (boreholes and reticulated supplies, gravity fed schemes, hand pumps, rainwater tanks, etc). For smaller settlements and isolated homesteads traditional sources still predominate. In larger villages improved sources are becoming increasingly widespread although problems with maintenance and the reliability of the supplies mean that it is not uncommon for people to periodically revert to traditional sources for short periods.

Whether women are collecting water from traditional or improved water sources, what is still standard practice for the vast majority living in the rural areas in most of eastern and southern Africa is the need to walk to and from the water source. A small fortunate minority have a well, handpump, standpost or rainwater tank in or close to their homes. For the vast majority (tens of millions of women and children throughout the region) a daily walk of at best a few hundred metres or at worst 10 km or more carrying water is the order of the day.

CURRENT STATE OF RAINWATER UTILIZATION

The number of household roof catchment systems in eastern and southern Africa almost certainly numbers several million at present and the number is increasing steadily.

In several parts of Kenya including Kitui, Nakuru, Laikipia, Baringo and Machakos, the use of household rainwater catchment systems is widespread. In South Africa too, despite a lack of formal projects to promote the technology, the incidence of small scale household rainwater collection is very high in some areas, e.g. N.Transvaal and Kwazulu-Natal where the number of households collecting rainwater exceeds 50% in many rural communities. The vast majority of these systems, however, are crude and simple often consisting of only a short piece of improvised guttering and an old 200 litre oil drum. Frequently, several containers will be used such as basins, buckets, oil drums, earthen pots, old bath tubs or in fact almost anything to help maximize the available storage capacity.

The reason larger tanks are not installed is mainly due to their high cost relative to household incomes. In rural Africa a new 5 m³ corrugated iron, brick or plastic tank would in many cases cost more than a family's entire annual income. Other reasons include the fact that householders may not be aware of just how much rainwater runoff can potentially be

collected. A single 50 mm rainstorm (an irregular but not rare occurrence in many parts of the region) could yield more than 2 m³ from a 50 m² roof equivalent to more than 10 times the volume of the commonly used 200 litre oil drum storage vessels.

There is also a gender issue involved regarding the decision whether or not to invest in an expensive storage tank. In almost all male headed households in Africa, men control the finances while women are traditionally responsible for fetching water. As a result male household heads may not perceive the benefits of the substantial investment in a rainwater tank from the same perspective as the women in the household since either way the men are provided with water delivered to the household. In female headed households, although the financial decisions are taken by women (familiar with the burden of carrying water), these households tend to be poorer often making the cost of a large storage tank prohibitive. While many millions of African householders may aspire to owning properly constructed rainwater catchment systems with large storage tanks, in reality these are restricted to:

- a minority of more affluent households who can afford the relatively high cost;
- households being assisted through one of the many donor or government funded projects;
- institutions such as schools and clinics.

Several small scale projects in Tanzania, Zimbabwe, South Africa, Botswana, Mozambique, Malawi, Uganda and elsewhere, Figure 1, have assisted several hundred households in acquiring systems (Farrar and Pacey 1974, Lee and Visscher 1990, Gould 1992). It is in Kenya, however, where numerous church and international donor funded projects (often working in conjunction with the government) have been most successful and many thousands of households have been helped to acquire properly constructed rainwater catchment systems with storage tanks ranging in volume from 1-15 m³. One of the most successful of these is the Catholic Diocese of Machakos projects which has been responsible for constructing around 5000 household systems in the last 10 years. Institutions especially schools with their large roof areas are particularly suited to roof catchment systems. In several countries in the region rainwater tanks are common at rural schools, e.g. Botswana, Kenya, Tanzania and Namibia.

KEY DEVELOPMENTS IN THE LAST 10 YEARS

Sub-surface Ferrocement Tanks A number of new ferrocement tank designs have been developed in recent years around the world, several of these were evolved predominantly from work in eastern and southern Africa. Amongst these large hemispherical underground ferrocement tanks with dome roofs and capacities of between 50-120 m³ were developed in Kitui, Kenya and several hundred have been constructed mainly at schools in eastern Kenya since 1980, the design has also been introduced in Tanzania, Namibia and Botswana. The main stages of construction are shown in Figure 2. Further details of the construction procedure are available in a photo manual produced by Nissen-Petersen (1992a).

Smaller sub-surface ferrocement tank designs have also been developed in Botswana since 1980 through the Arable Lands Development Programme (ALDEP). Several hundred of these tanks with volumes ranging from 5-60 m³ (but mostly 10-20 m³) have been built. Most are cylindrical with depths of up to 3 m and are constructed by pinning chicken wire and fencing wire to the sides of the excavation and carefully applying up to 3 layers of mortar. The design is based on one developed in the Pacific, Calvert and Binning (1977).

Surface Ferrocement Tanks Innovative approaches and designs for surface ferrocement tanks have also taken place in eastern and southern Africa. Although there has been so much cross-fertilization of ideas and approaches developed elsewhere, e.g. S.E. Asia and Australasia it is often difficult to trace the exact development of particular designs. One design, however, which definitely evolved in Africa is that of the wire reinforced concrete ring tank developed by the Catholic Diocese of Machakos in Kenya, De Vrees (1987). This design involves the use of two concentric corrugated iron ring moulds. Barbed wire reinforcement is wrapped around the inner mould and concrete is then poured between the concrete rings and compacted. Once the concrete has set a second stage can be constructed on top of the first. Another innovative aspect of this project is the implementation strategy. The project is almost entirely self-financing as it employs the use of a revolving fund system whereby a group of 10 households get together and each contributes 10% of the cost of a tank each month plus labour and certain materials such as sand and hardcore to help reduce the cost of construction. The project provides supervision, trained builders and technical advice as well as a small subsidy of about 25% of the cost. Each month a tank is built and in less than a year every member of the revolving fund group has a tank. The advantage of this system is that the relatively high initial cost of the 4.5 m³ tanks are spread over a 10 month period and a pool of labour to assist with construction and collection of materials is created. The construction of large surface ferrocement tanks with volumes of up to 46 m³ using a free standing formwork as illustrated in Figure 3 is an example of another design pioneered and developed first in Kitui District, Kenya where several hundred tanks of this type have been constructed mainly at schools. Nissen-Petersen (1992b). This design was also replicated in 1993 around Oshakati in northern Namibia. Currently, the design is being used as part of a training and pilot course in south-eastern Botswana to explore the possibilities of introducing this technology at all new schools in rural areas.

Apart from the innovative nature of the tank design itself, specially designed gutters incorporating splash-guards have also been developed to reduce any runoff loss due to splash or water over-shooting the gutters during heavy storms, Figure 4. Another important aspect of the implementation of this design has been the rigorous on-the-job training programme associated with the programme in Kenya involving certification of builders as well as the drawing up of contracts with schools to ensure the involvement of the community in terms of providing materials and labour.

ROCK AND GROUND CATCHMENT SYSTEMS

The collection and use of runoff from rock and ground surfaces is not a new technology in Africa. The utilization of rainwater in natural rock pools and excavated pits has taken place since ancient times. More formalized systems were, however, introduced in colonial times in certain areas suffering water shortages such as eastern Kenya and a few of these, now more than 40 years old are still in use today in Kitui district. Most of the original systems, however, fell into disuse or were not properly maintained. In the 1970's the technology was revived in eastern Kenya. In the 1980's around 100 new rock catchments were constructed in and around Mutomo and about 20 old rock catchment dams were repaired. The largest rock catchment dam built had a capacity of 6000 m³. At present around 200,000 people in N. Kitui depend on rock catchments for regular water supplies.

Rock catchment systems have also been built in small numbers in other parts of Southern Africa as well, e.g. Zimbabwe, Namibia and a few in Botswana. The quality of

the water from rock catchments is generally poor and it should ideally be treated before consumption or used only for non-drinking purposes. The system's evaporation losses can be high from the open reservoirs. Nevertheless, the large number of massive rock outcrops in eastern and southern Africa offer the potential for expanding the use of this technology substantially. Due to the fact most rock catchment dams are located above settlements, the possibility for gravity fed supply also normally exists.

A more innovative technology which is currently undergoing trials in the Kalahari desert in southwestern Botswana is a system using the side of a salt pan as a catchment surface, Figure 5. The Kalahari is flat and is covered predominantly with a thick layer of permeable sand. Rainfall normally infiltrates directly into the ground. Groundwater tends to occur only at considerable depth and is frequently saline. Pans which consist of depressions usually up to a few square kilometres in size filled with evaporite deposits do occasionally fill with rainwater after heavy showers for a few days. Slopes around the edge of the pans may rise 10 or 20 m above the pan floor. These are sometimes sufficiently steep to produce surface runoff as evidenced by small rills and gullies.

In Zutshwa in S.W. Botswana, a series of three 65 m³ sub-surface tanks have been constructed to collect this runoff and provide a water source for a Bushman settlement of around 250 people and their livestock. So far, the system seems to be working well although there is a problem of high turbidity due to very fine clay particles which are suspended in the runoff. A detailed discussion of this system shown in Figure 5, is given by Petersen (1993).

LESSONS LEARNT

Although there have been many very successful rainwater catchment system projects and technologies in eastern and southern Africa in recent years there have also been a few which have failed. These failed projects are important, however, as from them vital lessons can be learnt which can help ensure the success of future projects.

The most significant failure in the region in recent years has been that of the basketwork 'reinforced' Ghala basket tank design. Several thousand of these highly publicized tanks were constructed mainly in Kenya with volumes ranging from 1-10 m³ (but mainly at the lower end of the range). Billed as an appropriate 'low cost' solution to rainwater storage several projects were funded and initially developed well. The problems with the Ghala basket design mirrored those of the even more publicized bamboo reinforced tank design in S.E. Asia where 50,000 tanks were constructed in Thailand alone before the deficiencies in the design were recognized, Vadhannavittik (1987). As with the bamboo, the basket work frame of woven sticks in the Ghala tanks was intended to act both as an initial formwork and as reinforcement. In reality, however, like the bamboo it was subject to bacterial, fungal and termite attack. Within a few years the basketwork frame was either rotten or eaten away by termites and the tanks cracked and leaked badly.

The construction of the Ghala basketwork design has now more or less ceased, but it is still widely quoted and often recommended in the literature and even as recently as 1993 was being promoted at a workshop more than five years after the fundamental flaw in the design first came to light. Clearly there are two important lessons to be learnt here. First is that as a rule organic 'reinforcement' is not an appropriate material for use in water tanks. Second is the importance of thoroughly field testing any new design before encouraging its widespread implementation. In the case of another innovative design developed in Kenya in the early 1980's by the Diocese of Kitui involving the use of sisal reinforcement these lessons

were applied. Following thorough field testing of a few trial tanks, the sisal reinforcement tanks were found to suffer from unacceptable cracking problems and the development of the design was discontinued.

It is not only the technical aspects of a design which need to be rigorously tested and shown to stand the test of time. Many projects fail for socio-economic or cultural reasons as they fail to sufficiently involve the community or to address their real felt needs. A German funded rainwater tank project implemented near Kilifi on the Kenyan coast during the early 1980's provides a good example of this type of failure. The objective of the project was to increase access to improved water supplies through the introduction of rainwater catchment systems technology. The technology chosen by the implementing agency was a highly robust factory built 6 m³ ferrocement tank. Since these were beyond the means of the community the implementing agency decided to give the tanks to project recipients, subject to signing a contract agreeing to future repayments. Effectively, the project loaned them the equivalent of the cost of the tank and planned to start collecting repayments subject to a 6½% interest rate after a 2 year grace period. Due to the almost total lack of involvement of the community the project failed on several counts and problems began almost immediately. It was the responsibility of the tank recipients to erect gutters and downpipes. As a result of the lack of consultation with the tank recipients and their obvious lack of understanding regarding the technology few erected effective gutters. Several households simply hung a short length of gutter immediately next to the tank leaving most of the roof runoff to run to waste. Another component of the project which was clearly misunderstood was the fact that the tanks were provided on the basis that they would be paid for in future through instalments subject to interest charges. Most of the tank recipients seemed to view the tanks as a gift and the collection of repayments was extremely difficult. This resulted in the demise of the project as its sustainability depended on using funds generated from the repayments to fund the construction and implementation of further tanks.

Another critical lesson which has been learnt the hard way in the last 10 years is the vital importance of comprehensive and effective training in the techniques of tank construction. This is especially the case in relation to the construction of ferrocement tanks which require a relatively high degree of skill and workmanship as well as attention to detail and careful curing.

In the mid-1980's a project aimed at introducing 10 m³ and 20 m³ ferrocement rainwater tanks using cylindrical corrugated iron moulds, a method described by Watt (1978), was undertaken in Botswana. A single three week training course was conducted for prospective builders during which time 2 tanks were constructed. In the following few years around 150 ferrocement tanks were constructed at schools and clinics. In a survey of 46 ferrocement tanks conducted by the author in 1991, around a quarter were found to be suffering from leakage. This was so severe in the case of 4 tanks that they were no longer able to hold water at all. It was clear from the nature of the cracks that most had resulted from poor workmanship, dirt being mixed with mortar or insufficient curing. The tanks that were operating satisfactorily generally showed signs of better workmanship. This survey revealed the necessity for any future ferrocement construction projects in Botswana would need to be done in conjunction with far more rigorous training courses as well as thorough ongoing supervision and monitoring of construction.

A lesson which still does not seem to have been thoroughly learnt in many parts of Africa is the critical importance of properly constructed and maintained gutters and downpipes. Frequently, serious inefficiency or total failure of systems is caused simply because insufficient care was taken to erect gutters properly or to repair and replace faulty

sections of gutter or downpipe. Numerous examples of gutter systems only exploiting a fraction of the potential available roof catchment area have been observed by the author throughout eastern and southern Africa. In some particularly unfortunate instances standard designs developed by engineers and architects of systems with water collection efficiencies of 20% or less have been seen on housing projects comprising up to 80 units. Worse still horizontal gutters or gutters observed to be sloping partially away from the tanks have been frequently observed. These are basic mistakes, simple to avoid or rectify, but extremely wasteful if ignored. Given the relatively high capital costs of constructing the rainwater tanks, the poor installation and maintenance of gutters and downpipes can turn out to be an expensive mistake as it can greatly reduce the effectiveness of the systems.

CONCLUSIONS

During the last two decades the use of rainwater catchment systems in many localities throughout eastern and southern Africa has increased dramatically. Whilst most of the systems in use are of the small scale improvised variety the implementation of large durable surface and sub-surface tanks has also become widespread especially at schools and clinics. In some countries new innovative designs and implementation strategies have been adopted eg. Kenya, Namibia and Botswana. The potential for increased use of rainwater catchment systems in the future is enormous and due to the growing pressure on water resources in general and the trend towards sustainable development it seems very likely that the recent trend of increasing use of the technology will continue.

Several important lessons relating to both aspects of design and implementation have been learnt in Africa during the last decade. Prominent amongst these was the failure of organic 'reinforcement' in the Ghala basketwork frame tanks in Kenya. In addition the following aspects were identified as being of vital importance for the success of any project:

- i. involving the community in every stage of a project;
- ii. thoroughly field testing new designs before their widespread construction and promotion;
- iii. proper training and supervision;
- iv. proper design, maintenance and repair of gutters and downpipes.

The success of rainwater catchment systems technology in fulfilling its potential in Africa will undoubtedly depend on the extent to which many of the lessons from the past are learnt and to what degree similar mistakes in design, construction and implementation are avoided in the future.

ACKNOWLEDGEMENTS

Support for conducting fieldwork related to this paper was received from the University of Botswana. Assistance with drawings and typing was given by Mr G. Koorurwe and Ms E. Kamikubo respectively. Useful discussions and comments on the manuscript were provided by E. Nissen-Petersen and A. Gieske. Logistical and technical support and contributions have also been received from the Botswana Technology Centre, Gaborone and the Rural Industries Innovation Centre in Kanye in Botswana; and ASAL Consultants and the International Rainwater Catchment Systems Association in Kenya.

REFERENCES

- Calvert K.C. and Binning R.J. 1977, "Low cost Water in the Pacific Islands", Appropriate Technology, 4 (3), London, I.T. Publications.
- Cullis A. and Pacey A. 1992, A Development Dialogue - Rainwater Harvesting in Turkana, I.T.Publications, 103/105 Southampton Row, London, 126p.
- De Vrees, L. 1987, "Machakos Diocese Rainwater Tank Programme" Development Office, Diocese of Machakos, P.O.Box 640, Machakos, Kenya, 15p.
- Farrar D.M. and Pacey A. 1974, Catchment Tanks in Southern Africa: A Review. Africa Fieldwork and Technology, No. 6, Myson House, Railway Terrace, Rugby CV21 3HT, UK. 13p.
- Gould J.E. 1992, Recent Developments in Rainwater Catchment Systems, Waterlines, 11(1) p19-21.
- Gurusamy K and Gould J. 1993, Rainwater Catchment: Possibilities in urban and peri-urban Botswana. Proc. 6th International Conf. on Rainwater Catchment Systems, Nairobi, p117-128.
- Ladu M.B. 1993 Rainwater Harvesting in Nairobi: Possibilities and Challenges. Proc. 6th International Conference on Rainwater Catchment Systems, Nairobi, p83-89.
- Lee M.D. and Visscher J.T. 1990. Water Harvesting in Five African Countries. Occasional Paper 14. I.R.C., The Hague, The Netherlands.
- Nissen-Petersen, E. 1992a, How to Build a Cylindrical Water Tanks with Domes. (Volumes 23 and 46 cubic metres). Photo manual. ASAL Consultants / DANIDA, Nairobi, 33p.
- Nissen-Petersen E. 1992b, How to Build an Underground Tank with Dome. Photo manual. ASAL Consultants/DANIDA, Nairobi, 31p.
- Nissen-Petersen E. 1992c, How to Build and Install Gutters with Splash-Guard. Photo manual. ASAL Consultants/DANIDA, Nairobi, 14p.
- Petersen S. 1993. Rainwater Catchment from salt pans for domestic use in Botswana. Proc. 6th International Conf.on Rainwater Catchment Systems, Nairobi, p169-177.
- Vadhanavikit, C. and Y.Pannachet 1987, Investigation of Bamboo Reinforced Concrete Water Tanks. Proceedings of the 3rd International Conference on Rain Water Cistern Systems. Khon Kaen University, Thailand. C13: 1-6.
- Watt, S.B. 1978, Ferrocement Water Tanks and their Construction I.T. Publications, London, 118p.

Figure 1. Map of Africa showing countries cited.

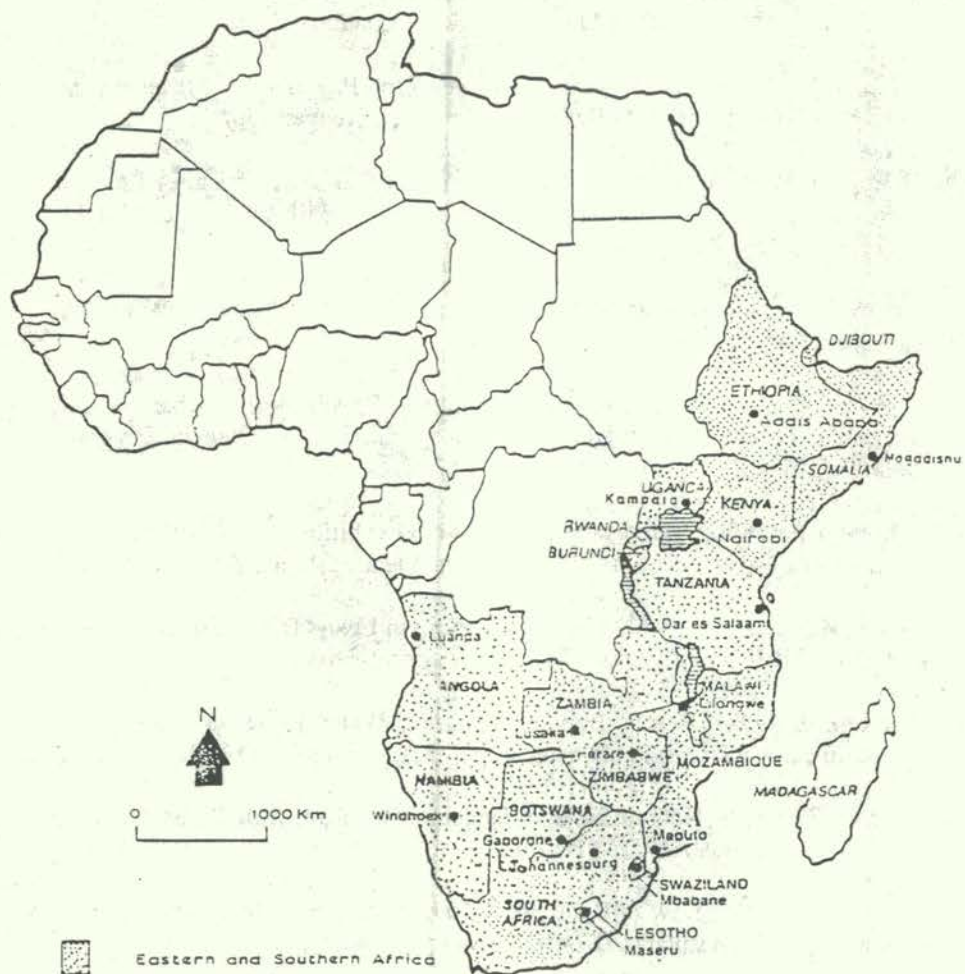
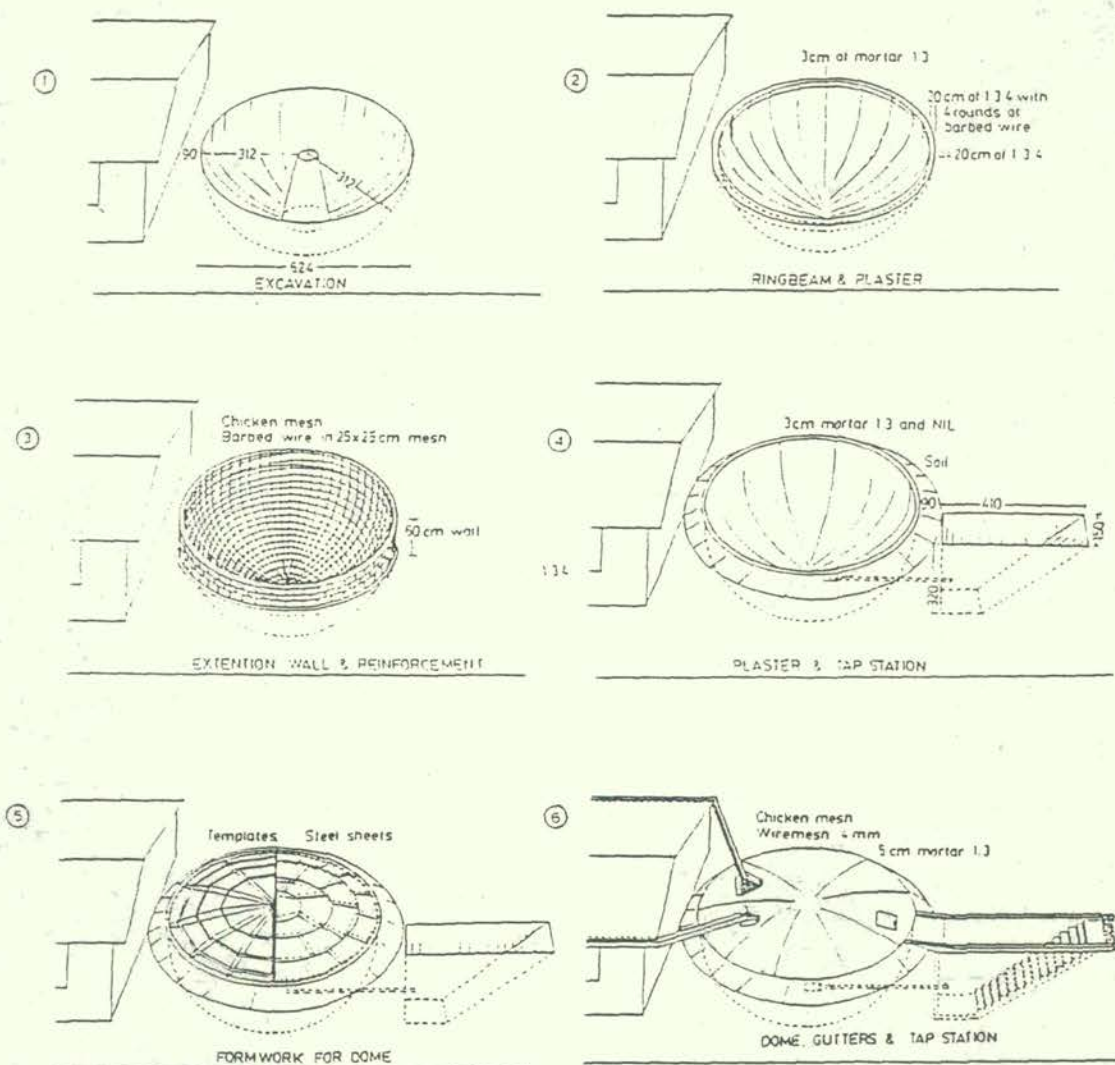
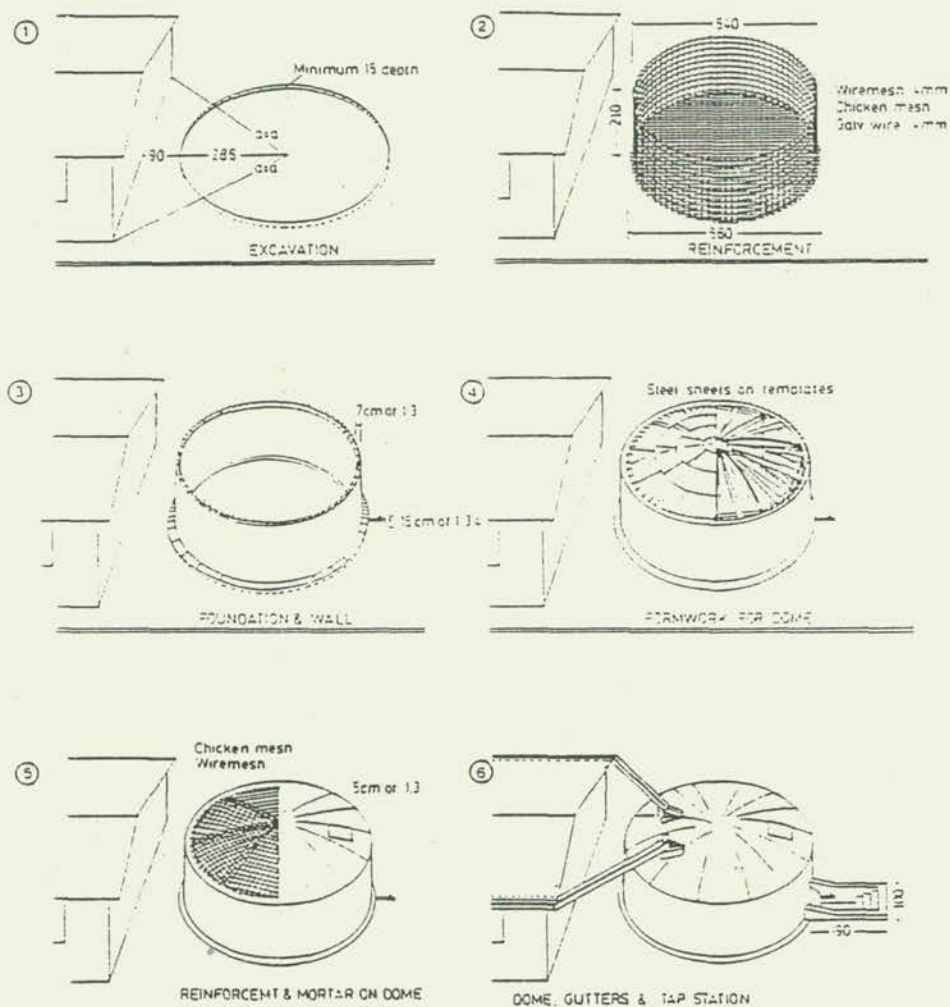


Figure 2. Sub-surface 80 m³ Ferrocement Tank Design
(Drawn by E. Nissen Petersen)



Note: All measurements in cm.

Figure 3. Surface 46m³ Ferrocement Tank Design
(Drawn by E. Nissen Petersen)



NOTE: All measurements in cm

Figure 4. Splash Guard and Hanging Gutter
(After Nissen-Petersen 1992c)

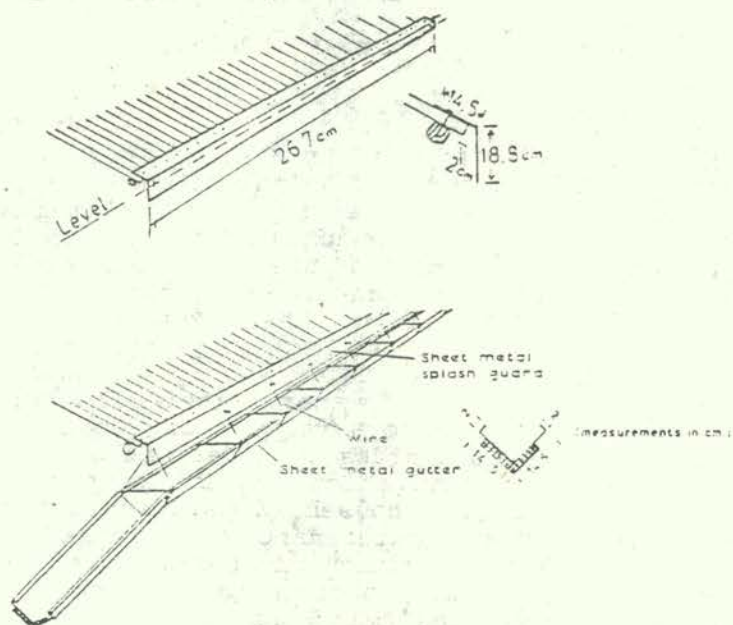
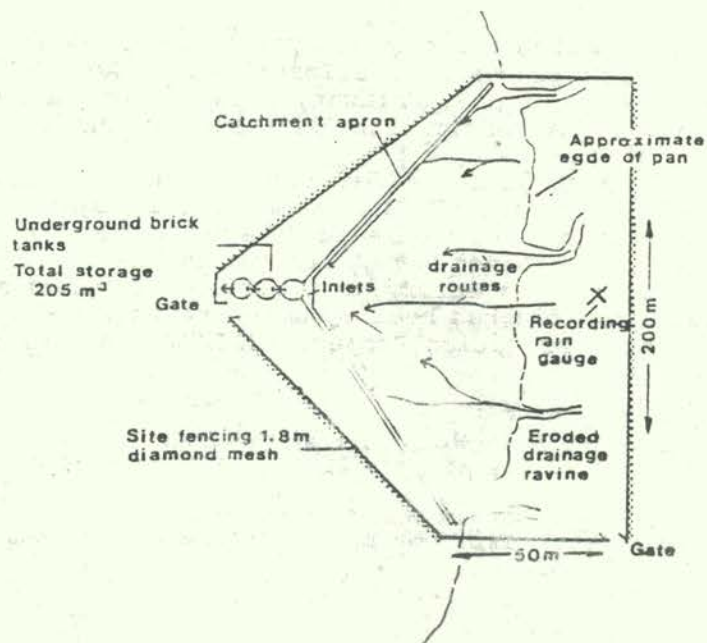


Figure 5. Pilot Rainwater Catchment Scheme on Zustshwa Pan Botswana.
(After Petersen 1993)



INDIGENOUS IRRIGATION SYSTEMS AND RESOURCE MOBILIZATION FOR UTILIZING RAIN WATER: A LESSON FROM THE HILLS OF NEPAL¹

K. R. Adhikari²

1. Abstract

The Irrigation Management Systems Study Group (IMSSG) at the Institute of Agriculture and Animal Science, Rampur, Chitwan, Nepal accomplished a resource inventory of 160 farmer-managed irrigation systems (FMIS) from the Tanahun District (mid-hill) of Nepal during June-December 1993. A part of the study examined the means and ways these irrigation systems, despite many constraints, collect and use rain water. Nearly half of these systems depend exclusively on monsoon rain for irrigation. The management of these systems ranges from very simple individual to complex collective efforts to collect and allocate this water. Water allocation methods change from continuous supply to a variety of rotational methods as the water adequate period shifts to a deficit period. Due to the hill environment, these irrigation systems have to mobilize a large amount of labor, both on household and crop area basis required for regular and emergency maintenance of intakes and canals. As a result, resource mobilization has become the primary activity for acquisition of rain water that in turn, seems to have an influence on the structure and many of the irrigation system FMIS institutions. It is realized that the farmers know much about the local environment with which they have been interacting for their sustenance. The study suggests that the irrigators be brought directly involved in exchanging ideas about problems and solutions for effectively harvesting and using rain water for dependable irrigation before outside technologies are introduced into the system.

2. Background

The Irrigation Management Systems Study Group (IMSSG) is one of the research groups at the Institute of Agriculture and Animal Sciences (IAAS), Rampur, Chitwan, Nepal involved in the studies of issues related to irrigation development and management in the country.

The IMSSG completed a detailed inventory study of irrigation resources of more than 250 farmer-managed irrigation systems (FMIS) from east Chitwan and north-east Tanahun during May 1992 - December 1993. Under the project *Nepal Irrigation Institutions and Systems (NIIS): Resource Inventory and Process Documentation* beginning June, 1993, the team has been documenting intervention processes of the East Rapti Irrigation Project (ERIP); its goal to rehabilitate

¹Paper Prepared for Presentation at the "7th International Conference on Rainwater Catchment Systems", June 21-25, 1995, Beijing, P. R. China.

²Lecturer, Department of Soil Science and Agricultural Engineering, and Member of IMSSG, IAAS, Tribhuvan University, Rampur, Chitwan, Nepal.

and strengthen a large number of FMIS in east Chitwan. As a part of the project activities, IMSSG augmented the NIIS-database from the original 127 to 173 cases of irrigation systems from different parts of the country. In addition to it, it has recently established a geographical information system (GIS) laboratory at the campus. With this, activities are underway exploring GIS applications to link various bio-physical and institutional dimensions of irrigation-forestry inter-linkages. This provided the capability to analyze geographically referenced information in the study area of east Chitwan. Since the IMSSG team constitutes capable faculties from various disciplines, it focuses on applying multi-disciplinary approach to all kinds of resource-base related to irrigation development.

In Nepal, FMIS possess long history and spread over the largest area in contrast to agency-managed systems (AMIS). Ostrom (1992) states that strong tradition of community, operation and management skills, organizational capabilities and ownership feelings with the water users have permitted FMIS to exist for generations. Most of these systems in Nepal have been fed by monsoonal rain. The documentation of these users' knowledge and practices has become a matter of basic concern to understand resource problems related to irrigation and then to build on the indigenous technology.

This paper is a component of the irrigation resource inventory of north-east Tanahun wherefrom, the information on physical, hydrological, social, agricultural, and organizational aspects of the FMIS were elicited.

3. Rationale

In the context of Nepal, a recent estimate indicates that the irrigated area under FMIS is about 675,000 ha as against 275,000 ha under the public sector irrigation development (Ansari and Pradhan, 1991). The FMIS alone account for over 70 percent of the irrigation development of the country. The existence of more than 17,000 FMIS have been reported both from the hills and the Terai (Yoder and Upadhyay, 1987). Despite abundant water resources, only 20 to 25 percent of the hill area in the country is irrigated (Gorkhaly and Shrestha, 1981). Roughly, over 90 per cent of the irrigation development in the hills is initiated and managed by the local farmer themselves (WECS, 1991). Approximately 40 percent of the national cereal crop requirement is produced from irrigated farming under FMIS in Nepal (WECS, 1991; Shrestha, 1990). Despite high priority and investment of the government in the AMIS, these schemes in comparison with the FMIS appear to perform poor (Shukla et al, 1993). This may imply that the increasing demand for food in the hills can be met in part by promoting these FMIS and bolster the output from irrigated agriculture.

Individual farmers often in the hills, acting alone, can seldom acquire water for irrigation. Martin and Yoder (1988) state that construction and maintenance of a canal structure to divert and convey water over a large distance usually requires investments beyond the capacity of a single farmer and the locations to which it can be conveyed are limited by the topography. Once the

irrigation canal has been constructed, irrigation systems have other prominent tasks to be accomplished. In this regard, one of the critical activities is the resource mobilization for acquisition and distribution of water (Martin, 1986; Pradhan, 1988; Pradhan et al, 1988). The labour, cash and materials are mobilized from among the beneficiaries in the systems under study. The most important is the labour contribution for operation and management (O&M) of the system. However, the basis for mobilizing these resources may differ from system to system (Pradhan, 1989). Generally external supports are also granted to the system when the O&M of the system is beyond the capacity of the farmer. Thus the internal labour mobilization is of primary concern for the sustenance of these systems.

The major approach for diverting rain water into the system areas is the damming of seasonal and/or perennial streams. Labour contribution, among others, is the most preferred and common tradition observed in all the FMIS in the study area. The discussion section of this paper shall focus on how these farmers mobilize their labour resources to acquire water as well as for O&M and how they allocate water for irrigation. In addition, the paper will also provide relevancy of users' labour burden with system sizes; organizational patterns and crop productivity as well as their institutional aspects. The strength of this study lies in the fact that unless the users' knowledge and practices are documented and understood, the development packages may not be well received by the people for sustained use and management of the resources.

4. Methodology

The study area in Tanahun district is located between longitudes 83°57' to 84°34' East and the latitudes 27°36' to 28°05' North covering a geographical area of 1568.4 square kilometers (Poudel et. al., 1993).

The inventory technique has emerged as a multi-disciplinary approach capable of being applied to all types of resource bases (Messerchmidt, 1991). After getting a fair amount of success in documenting information on irrigation resource of Chitwan district (plain area), IMSSG applied the technique to study FMIS in Tanahun (hill area) district. This methodology included preparatory work prior out to the field in which were collected the secondary data related to irrigation of the projected area. Previous reports and maps were collected from different sources such as the District Development Council (DDC), District Irrigation Office (DIO), District Soil and Watershed Conservation Office (DWCO), Agricultural Development Bank (ADB), District Agriculture Office (DIO) and International Irrigation Management Institute (IIMI)/Nepal.

The inventory checklists were developed in english and translated into Nepali after pretesting. Based on the experience of pretesting in the field, some necessary changes were also made in the checklist to capture information more effectively. The key informants from each irrigation system were identified. The semi-structured group interviews were conducted in each irrigation

system. The respondents included the experienced water users and elderly persons who could tell about the irrigation development and management of the systems in the past and present context. Attempts were made to make the interviews as participatory, informal and iterative as possible. Focusing through the checklist, information was recorded. The dialect for the local terms used by the irrigators were recorded and introduced into the updated checklists to get a sense of what they really wanted to express thus minimizing the communication gap.

System walk through was made with the beneficiaries and recorded the information on physical characteristics of the system. This cross checked and reconfirmed the information gathered from the respondents. Also by doing so, the study team availed an opportunity to exchange ideas with farmers out of their busy working hours in the field.

5. Resource Mobilization

5.1 Initial Construction

The history of the majority of irrigation systems dates back to unknown past. Even the elderly persons could not figure out nor did they have any information recorded on the amount, type and basis of resources used in initial construction. It is learnt that the Agri - a person skilled and traditionally worked in the mining industry, used to work also in construction of the canal in early days. Prior to 1951 during the Rana Monarchy in Nepal, the first poet of the Nepalese language Bhanubhakta Acharya was sentenced to imprisonment for initiating the construction of Bhanu Baraha irrigation system as all development works at that time were restricted.

5.2 Rehabilitation and System Improvement

The study on rehabilitation and system improvement works carried out in the irrigation systems of the study area reveals that in 72 (45%) systems no records of rehabilitation/improvement is found; 40 (25%) systems mobilized their internal labour, cash and kinds resources (not quantified) and 48 (30%) systems received some external assistance. In most cases the irrigators contributed substantial amount of their labour. In few cases only they paid for hired labours. In majority systems, the labour contribution is made on household basis. The rehabilitation or system improvement works included extension and lining of the canal, headwork improvement by providing gabion boxes filled with stones across the stream to channelize the water into the canal, construction of the spurs to protect the canal as well as the service area from stream bank erosion, construction of permanent headworks, erection of dry stone walls across the erosion prone zones to stabilize the canal banks, shifting of the diversion weirs to upstreamside, fixing of piped culverts for cross drainage works and make structures for distribution of water.

A number of external support agencies such as Irrigation Line of Credit, a branch of World Bank; District Irrigation Office, Small Farmers Development Program of Agriculture Development Bank/Nepal, Hill Food Production Project (HFPP), District Watershed Management

Office, and the Department of Road have been found to be the major agencies providing assistance for rehabilitation and improvement of some of the irrigation systems in the area.

5.3 Operation and Maintenance (O&M)

The irrigators generally prefer to mobilize their labour resources than cash or in kind for O&M activities. These activities are categorized as regular and emergency ones based on the nature of particular canal work and its urgency (Table 1). There are 74 (46%) systems that perform regular O&M activities on landholding basis, the same number accounts for regular O&M but on household basis and 12 (8%) systems have other unidentifiable bases for similar regular activities. However, the labour mobilization strategy changes greatly when an emergency is encountered. In order to respond to an emergency situation, the data on Table 1 demonstrates a significant increase in demands for labour mobilization on household basis (from 46% to 64%) and reduced demand (from 46% to 23%) in the case of landholding basis

Table 1. Irrigation Systems (number) based on Labour Mobilization

O&M activities	Major basis for labour mobilization			Total no. of systems
	Landholding	Household	Others	
Regular	74 (46.25)	74 (46.25)	12 (7.5)	160 (100)
Emergency	37 (23.10)	102 (63.75)	21 (13.15)	160 (100)

Values in parenthesis indicate percent distribution of FMIS.

Other bases of O&M for regular and emergency works include the following:

- 1) contribution of labour by winter wheat and spring rice growers which are not so common with larger areas, 2) contribution of more labour by big land-holders during emergency, 3) mutual understanding among the irrigators, 4) amount of water share, 5) more labour contribution by the users residing near the system intake meaning that they have some or more land in the headend of the system,
- 6) those who want to transplant their paddy earlier may go first to intake point for water acquisition, and 7) some households with more male members in the family may contribute more labour to canal works.

The intakes and canals of the seasonal systems are repaired and cleaned more frequently as compared to the case in perennial systems. The emergency cases are less in perennial systems where the water flow is more of a consistent in nature and thus less floods and sediment depositions in intakes and canals. The following section 5.4 deals with the relative burden on the appropriators for system operation.

5.4 Household-based Labour Burden for System Operation

The FMIS under study are highly skewed in terms of their sizes (1-60 ha). Thinking that this variation in sizes might be one of the practical ways to relate the characteristics of system

operation and maintenance as well as systems performance, four system size classes were formed (Table 2) such that each class represents its relative order of dominance in the field.

Other things being equal, the labour burden on system operation and maintenance was found inversely related to the size of system (Table 2). The number of systems and average man-days/household/system/year (AMHSY) decreased with increasing system size classes in the study area. The majority of the irrigation systems (72%) have service area less than eight hectares in size where AMHSY was found to be the highest. In other words, the larger the system size the smaller is the AMHSY. This trend of AMHSY also resembles with that of the average cropping intensity (ACI), i.e., the lower the AMHSY the lower is the ACI. This indicates that the bigger systems have less annual crop production compared to the small sized irrigation systems. Relatively poor institutional rules for labour mobilization, ignorance of the tail or head-enders, helter-skelter settlement of the beneficiaries, use of multiple sources of water for irrigation, provision for the use of the drainage water from adjacent higher lands and, or from other systems have been found to be some reasons for such occurrence with the larger systems. As per the respondent water users, these AMHSY values indicate only the minimum burden on the users for system operation and the upper limit can go still higher and varies every year with flood effects.

Table 2. Relationship of System Size Class with Labour Use for O&M

System Size Class (ha)	Irrigation Systems		AMHSY	ACI
	Number	Percent		Percent
1-8	112	72	8.3	207
8-16	23	15	7.4	200
16-32	12	8	5.7	170
32-60	8	5	4.9	166
	155	100	$\bar{x}=66$	$\bar{x}186$

AMHSY=Average man-days/household/system/year

ACI=Average cropping intensity

On the other hand, when labour mobilization is viewed by relating it with the organizational patterns and the service area at system level, one can see situations that differ from the above. The computed average service area per system under formal, informal, ad hoc and in systems without organizations (for definition see section 7.1) are in the order of 16.6, 8.6, 4.9, and 7.0 ha, respectively (Table 4). Number of labour mobilized per system per year also decreases significantly from 248 in formal, 169 in informal, 78 in ad hoc and 63 in systems without organizations. This demonstrates that the formal and informal systems are comparatively more capable of mobilizing higher number of water users than ad hoc and systems without organizations. When viewed upon combining Table 2 and 4, a general idea can be drawn that the larger systems do not necessarily utilize more labour.

However, as the water users develop and tie themselves up in an organized manner there is likelihood of more labour contribution for system management.

6. Water Allocation and Distribution

6.1 Water Allocation

Less than 5-7 percent of systems practise inter-system water allocation methods. Because of their smallness in number, the discussion is confined only to the level of intra-system water allocation methods. These methods have been classified into four main categories: continuous/free supply, rotational allocation, first come first basis and users' consensus. Regardless of water adequacy in the canal, the water is supplied continuously in 41 percent (52+14=66 systems under free flow) systems. However, 50 (68%) seasonal systems do not practice continuous supply of water during deficit period. The number of perennial systems (40) with continuous supply during adequate period is also greatly reduced (14) as the sources become weaker and the deficit period takes over. Altogether 79 (50%) systems both under seasonal and perennial sources practise various rotational water allocation techniques even under water adequate period. However, during water deficits

Table 3. Distribution of Irrigation Systems by Water Allocation Method

S.No.	Water Allocation Methods	Water Adequate Period			Water Deficit Period		
		P	S	Total	P	S	Total
1.	Free flow in the Canal/ Continuous supply	40	12	52	14	0	14
2.	Rotational allocation						
	Time/Area Relation	12	36	48	26	32	58
	Time/Soil Relation	0	1	1	2	1	3
	Area/Labor paid	1	0	1	1	0	1
	Involvement in Canal supervision works	0	0	0	0	1	1
	Discharge based and area relation	0	2	2	3	2	5
	Based on Canal branches	1	1	2	1	0	1
	Priority to block locations and/or head and tail	18	7	25	20	14	34
	Sub Total	32	47	79	53	50	103
3.	First come first basis	1	3	4	1	3	4
4.	Users' consensus	13	22	35	18	21	39
	Total	86	74	160	86	74	160

P = Perennial System, S = Seasonal System

period, about 103 (65%) systems adopt a rotational allocation method. Under conditions when water adequate period shifts to a period of water deficiency, about 40 percent more perennial systems and only 6 percent more seasonal systems adopt rotational allocation of water.

Interestingly, there are other systems, 35 during water adequate and 39 during water deficit periods, that have been operating without having any specific method for water allocation. In this case, the users' consensus appears to be the main basis for water allocation. The reasons noted for this are the easy nature of systems to operate, provision of drainage water and no existence of WUOs or lack of strong WUOs that can otherwise put some impedance for getting water freely. A long water deficit period prevails in the study area from September/October through April/May. The reduced canal discharge during this period forces majority of the systems to go for more restrictive water allocation method. A careful look at Table 3 exhibits that the dominant water allocation method is based on time/area relation in 67.5% or 106 systems followed by priority given to block locations or head to tail rotation in 37% or 59 systems. Small number of other systems have water allocations based on time/soil relation, area/labor contribution in the canal, involvement in canal supervision, canal discharge/area relation and the number of canal branches of the individual system.

6.2 Distribution of Irrigation Water

In these hill irrigation systems, a peculiar thing observed is that in many systems have their field outlets directly connected to different sections of the main canal. Under adequate water conditions, several systems keep all outlets open to get continuous supply of water, especially during paddy season. The irrigators devoid of such direct access to the main canal get water either through a plot to plot distribution method or through a narrow water course, locally called *Ahad*, drawn at one corner of the front plot that is directly connected to main canal. However, rotational distribution of water starts operating in about 65% systems as water deficit period approaches. Rotational distribution can also be observed in 60% systems during water adequate period. It is found to be due to long conveyance length which is quite vulnerable to water loss by leakage and seepage.

The most sustainable distribution has been the rotation system where the farmers have fixed the time duration for unit area to be wetted. There are 59 (37%) systems where rotation is practiced between headend and tailend area of the system. In order to make the rotational supply more effective some 2% systems follow distribution of water based on the soil type. In Patal system, a team is formed to supervise the canal daily during active growing season crop. In about 4% systems, the area to be irrigated depends upon the discharge capacity of the canal. Here, more the discharge capacity of the canal more is the area to be wetted. However, there is a general understanding that everybody in the system must get water for transplanting paddy before it can be redistributed to the field where they have already used water for transplanting. It is widely accepted that every user should transplant paddy first.

So far as the time and frequency of water distribution is concerned, it ranges from an hourly rotation basis to once a week which could be either in the morning or day or night turns. In many cases, locally available materials like logs and earthen slices, locally called Chapari, have been used as structural devices for water distribution. In order to provide equitable water to the users, a group of persons from within the system can also be observed monitoring the canal occasionally to check against violation of water rotation by some unidentifiable persons.

7. Water-users Organizations and Institutional Rules

7.1 Nature of Organizations

A great diversity in organizational patterns could be observed among these irrigation systems. Considering this variation, the irrigation organizations have been conveniently put to either one of four types of water users' organizations (WUO). Out of 160 systems, 26 (16%) formal, 75 (47%) informal, 25 (16%) ad hoc and 34 (21%) systems have been found without WUOs. To say that irrigation organizations are formal, is not to say that all of them have well developed rules-in use (e. g., record keeping). Similarly, to say some systems informal or ad hoc does not mean that they do not have any rules-in-use.

Table 4. Labour Mobilization and Record Keeping by Organizational Types

Water Users Organizations	Labour	Record Keeping	Average Service
	Mobilization/system		Area/system
	Man-days/yr	No. of Systems	hectare
Formal (n=26)	248	16 (62)	16.6
Informal (n=75)	169	7 (9)	8.5
Ad hoc (n=25)	78	1 (4)	4.9
No WUOs (n=34)	63	1 (3)	7.0

Values in parenthesis indicate percent of the irrigation systems
WUO = Water users organization

The systems that possess distinctly organized group to work as an executive body and have set rules are regarded to have "formal" organizations. However, such systems may or may not have been registered officially. But it is known that the government agency do not consider such systems as formal unless they are officially registered. "Informal" organizations, on the other hand, do not have any distinctly organized groups of water users. One or few water users feel accountability of water management activities in the system. Such farmers are either opinion leaders or are among those who have large farm size and reside near the service area or have sufficiently contributed in the development of system by themselves or by their forefathers or are progressive in nature. They generally call meetings, co-ordinate activities of water management and resource mobilization but generally do not keep their rules and decisions written and also, do not have sanctioned rules or regulations, nor do the users impose any duty on such

leader farmers. These leaders are seen to work as long as the users respect them and are obliged by users for their leadership.

In the case of "ad hoc" organizations, neither the systems have any set rules or identified leaders for system management. Yet certain norms for participatory activities appear to be working. Some examples are: 1) All water users have understanding to meet together and participate in canal cleaning and intake repairs. 2) generally they have mutual understanding to meet, discuss and find the proper way of conflict resolution, especially by regulating water rotation, 3) meetings are held to fix the dates for canal cleaning and maintenance and setting rules against absentees and 3) the farmer that wants water first in the season has to inform other farmers (locally called as *Urdu*) regarding damage and repair of the canal and to meet at work in the canal and intake.

Those systems devoid of any organization have no clear norms for system management. The system work depends upon the personal interest of the individual farmer. Laborious and conscious farmers appropriate much water more frequently than others. Those who want to transplant rice early go to the intake and bring water up to his own field outlets only. The same tradition follows for monsoon and winter crops. None of the farmers mind or oppose such activities regarding water use. The discussion on institutional arrangements in the following section 7.2 will indicate the relative effectiveness or strength of these irrigation systems.

7.2 Rules and Regulations for System Operation

A few pertinent variables have been selected which characterize the effectiveness of irrigation organizations in institutional development (Table 4). The findings indicate that out of 160 systems inventoried, only 62% formal, 9% informal, 4% ad hoc

Table 5. Distribution of Irrigation Systems by Nature of Fines Imposed on Defaulters and the Nature of Water Users Organizations

Nature of Fines	Type of Water Users Organizations				Total
	Formal WUOs	Informal WUOs	Ad hoc WUOs	No WUOs	
Excuse	-	1	-	-	1
Monitory fines	1	1	-	1	3
Equal to one days labor compensation	1	3	-	-	4
No fine	6	8	3	4	21
Equal to two days labour compansetion			-	-	1
Cessation of water turns	1	-	-	1	2
Grand Total	9	14	3	6	32

and 3% systems without WUOs keep written records of labour mobilization for O&M activities.

From above, negligence in record keeping appears not only in ad hoc and the systems without WUOs but also in systems with formal and informal WUOs which gives a sense of looseness in operational rules with these systems. However, higher number of labour mobilization in formal and informal WUOs is an indicator of their being in somewhat stronger position than in ad hoc and the systems without WUOs.

In order to know other institutional arrangements, a sample of 32 representative potential systems is drawn from within 160 systems (Table 5) and analysis made for nature of fine imposition on defaulters. This indicates that 21 systems do not impose any kind of fine to the defaulters which include 6 of 9 formal, 8 of 14 informal, 3 of 3 loose or ad hoc and 4 of 6 no-WUO system types. This gives a general picture of where do these systems occur in the institutional profile. Table 5 also shows evidence that other kinds of fines and sanctions are also not implemented properly which could otherwise reflect the capability of the irrigation systems.

8. Crop Performance

The irrigation systems strive for supplying water mainly to grow lowland paddy. Depending upon its availability, wheat is also grown during winter dry season. In Table 6, a relation between different WUOs and productivity of major crops is presented. Generally all systems grow paddy over the entire crop area during monsoon season. However, as the winter dry season approaches, the lesser number of irrigation systems practice wheat cultivation.

Table 6. Crop Productivity of Systems under Different Water Users Organizations

Water User Organizations	Paddy		Wheat	
	% systems	Yield (qtl/ha)*	% systems	Yield (qtl/ha)*
Formal (n=26)	100	39	85	18
Informal (n=75)	100	36	73	16
Ad hoc (n=25)	100	34	52	16
No WUOs (n=34)	100	31	67	17

* = The yield values are expressed in the nearest whole number.

A maximum of 85 percent systems under formal WUOs, followed by 73 percent informal, 67 percent systems without WUOs and 52 percent systems under ad hoc WUOs grow winter wheat. Unlike wheat yields, a greater difference in paddy yields can be observed when these WUOs are compared among themselves. In both cases of paddy and wheat, the irrigation systems under formal WUOs produce consistently higher yields than any other systems. From here, it can be said that among several factors affecting crop yields, the water users organization is also an important factor that has potentiality to alter crop performance through O&M of the system.

Based on data in Table 4 and 6, the role written records and the type of organization play in crop productivity could be realized. As reported by Kyi (1990), Nepal has the lowest (1.76 t/ha) paddy yield in comparison with its yields in seven Asian countries, The Philippines, Thailand, Sri Lanka, Malaysia, Indonesia and Korea (6.38 t/ha). This does not appear in agreement with the findings of this study given in Table 6. It is not unusual that the national average values are mostly smaller than the values obtained from within a small area. However, it is worth saying that crop yields in the study area can still be augmented through better utilization of the production resources such as irrigation.

9. Environmental Concerns

The study area is located at the foothill of the middle mountainous region (LRMP, 1986). The annual precipitation is more than 2000 mm and 76% of which, occurs during monsoon season, beginning from June to September (WECS, 1991) indicating the super humid climate. Due to the shortage of arable land, the hill people are forced to cultivate steep and unstable slopes that has invigorated the erosion and flood processes causing low crop and forest yields in Nepal (Gorkhali and Shrestha, 1981). The people whose livelihood is directly associated with the use of the surrounding watershed tends to provide not enough space to nature. Consequently, environmental degradation has become a common theme in Nepal (Adhikari, 1993). The report on irrigation resource inventory of north-east Tanahun (Poudel et al., 1993) has also raised and stressed this issue to be a matter of vital concern for sustainability of the FMIS in this area.

Table 7. Variation in Irrigation Headworks by Water Users Organizations

Water Users Organization	Types of Headworks				Total System (No.)
	Permanent	Semi- permanent	Temporary	Non existent	
-----No. of Systems-----					
Formal	3	11	12	-	26
Informal	-	9	64	-	73
Ad hoc	-	4	22	-	25
No WUOs	-	2	29	3	34
Total	3 (2)	26 (16)	126 (80)	3 (2)	158 (100)

Values in parenthesis indicate percent, * = Two headwork data missing.

Table 7 shows that there are temporary (80%), semi-permanent (16%) and permanent (2%) headworks in the study area. With 2 percent systems no signs of headworks seem existing. Majority of the headworks are of temporary type falling under informal, systems without WUOs and under ad hoc types of irrigation organizations. All permanent headworks (3) are owned by formal systems, and all non existent headworks (3) owned by systems without WUOs. In the

context of systems in the study area, frequent floods, changing courses of the streams, landslide and erosion, seepage and leakage of water through the canal, canal breaching, deforestation and long canal routes through porous and fragile hilly terrains have been the pronounced factors challenging the sustainability and productivity of these systems. As of now, under any harsh environmental conditions the utilization of resource particularly the labour and skill with the farmers have been the frontiers somehow to keep the systems going.

10. Conclusion

The irrigation systems in the study area are largely indigenous in nature that have been sustained for generations. Only a small fraction of these, have been able to obtain external supports for O&M of the system. Thus, O&M activities required by the system have been carried out by mobilizing labour in substantial amounts from within the beneficiaries. The labour mobilization strategy keeps changing according to the season and to the degree of urgency for the particular work in the canal. Households form the major basis than any others for labour mobilization. In smaller systems, individual water users contribute comparatively more labour for O&M than the users in larger systems. This indicates more labour burden on the users of smaller systems. On the other hand, more labours are mobilized under registered and informal systems compared with ad hoc and the systems without WUOs. The systems with formal WUOs hold the largest service area than others.

Irrigation water is allocated both at inter and intra-system levels. Generally inter system allocation is made at the water source. Both systems sharing water get as much of it as they are entitled by some traditional rules or users consensus. At intra system level, majority of the seasonal systems undergo water allocation practices long before the water deficit period approaches, while majority of the perennial systems still continue with the free flow of water in the canal even under what they call water deficit period. Water allocation in proportion to the size of landholding and water distribution from head to tail or blockwise distribution are commonly observed practices. Except in a few cases, no industrial elements as devices for water distribution are found.

More than 75 percent of systems are not yet formalized. Compared to systems under other kinds of WUOs, the formal ones do not appear to be distinct and much superior in terms of imposing fines and sanctions to defaulters. However, labour mobilization, condition and types of physical structures and crop yields are relatively appreciable in these systems. Physical characteristics of these irrigation systems are such that intakes are located in one of the streams or local creeks. More than 80 percent of their intakes are supported by boulders, stones and logs with mud facings to which we call temporary or brushwood type headworks. Some stretches of tunnel for passing water along the rocky portion are commonly observed canal features. Due to combined effect of topographical deficiencies, loose soil material and frequent flood

ravages, many canal structures are subjected to damage that deem costly for restoration from farmers' efforts alone for efficient use of water.

11. Recommendations

From the foregoing, it is advisable that several systems that have still informal WUOs or are operating under ad hoc basis or have no WUOs, need to be registered first so that a major criteria is met for securing external supports from governmental or other funding agencies. It implies that keeping the benefit of their own mechanism aside, there should external supports be stressed. An attempt should be made to convince the unorganized groups of all kinds to learn quickly the benefits of WUOs in terms of better management of the system, higher crop yields, optimum use of all kinds of resources and for better community relations.

While there is ample evidence of set rules and regulations in the organization and management of irrigation systems, these must be in written forms and according to time and situation, every kind of deletion, addition, and modification in these rules should be made through joint meetings of all users for work in harmony and for lasting improvement of the system. Effective traditional rules and underlying principles that are still keeping group coherence should not be impaired while attempting to improve the organizational and institutional efficiencies of the system.

Water is also called "the double edged sword". Negative consequences occur when it is either in excess or is scarce in the field. It is recommended that the farmers should find a practical way to safely remove excess water during rainy season and also utilize maximum water in dry season by stopping all kinds of leakages so that the quantum of water is increased for irrigating crops as per requirement.

The spirit of cooperation with the farming community is needed everywhere in O&M of the system, and emphasis must be made to involve the group members at decision making process, different stages of implementation and application, and at evaluation and future program development for the beneficiaries. There must be a gross calculation of the annual cost of repair and maintenance, seasonal as well as permanent labour requirement, time allocation for water and labour works, agricultural inputs and their transportation considerations and for assistance from the people outside the system.

The farmers in these hills during rainy season have to face several problems and consequences. Flood damages not only the headwork, canal and water sources but also the fertile land of the farmer. There is also an increased shortage of labour during this peak work season, inputs transport difficulties from distant markets, inconsistent water flow in canal for transplanting paddy, and the poor economics of farmers compound their problems in a quite big way. In order to improve the livelihood, there must be a permanent endeavour of systematic planning and organization, a multi-disciplinary approach of irrigation management, meteorology, soil science, agronomy, horticulture, sociology and community development to tackle the temporary and permanent problems

involving farmers at all levels.

Consideration of users' local expertise and practices may help a lot to identify short and long-term problems and their possible remedy that supports planning for the development of dependable irrigation programmed in future.

From learning of the practices of FMIS, some desirable changes for improvements seem possible in government managed systems. It is extremely important that water should be considered by everyone in the system as a public property and not that of the government property. Such perception when conceived, the participatory management and utilization of any available quantum of water is enhanced.

Acknowledgements

The author would like to express his sincere gratitude to International Irrigation Management Institute (IIMI), Kathmandu for providing necessary funds that made this study possible. The help rendered by the author's co-workers of (IMSSG), Agricultural Campus, Rampur involved in the study are duly acknowledged. Dr. G. Shivakoti, coordinator of the Rural Resources Study Programme, and N. P. Gupta, a senior sociologist, IAAS, Rampur, Nepal as well as C. M. Schewik and Y. F. Lam, Ph. D. scholars in the political science at Indiana University, USA are thankful for their thoughtful comments for improvement of this paper.

Bibliography

- Adhikari, K. R. 1993. Documentation of soil fertility: An experience from irrigation resource inventory of north-east Tanahun and east Chitwan valley, Nepal. *Inst. Agri. and Anim. Sci. J.* 14:39-47.
- Ansari, N. and P. Pradhan. 1991. Assistance to farmer-managed irrigation systems: Experience from Nepal. Ministry of Water Resources, Department of Irrigation, Kathmandu, Nepal.
- Gorkhali, P. P. and M. M. Shrestha. 1981. Irrigation water management and use at the farm level in the hills. Proceedings of the seminar on "Nepal's experience in hill agricultural development." March 30 - April 3, 1981. Kathmandu. Nepal.
- Kyi, K. M. 1990. Resource mobilization in irrigation management: Myths and realities in a comparative perspective. Proceeding of a workshop on "Major irrigation schemes in Kandy, Sri Lanka." February 22-24.
- Land Resource Mapping Project (LRMP). 1986. Land systems, land capability and land utilization report. Kathmandu. Nepal.
- Martin, E. D. 1986. Resource mobilization, water allocation and farmer organizations in hill irrigation systems in Nepal. Unpub. Ph. D. dissertation. Ithaca. NY. Cornell University. USA.
- Martin, E. D. and R. Yoder. 1988. A comparative description of two farmer-managed irrigation systems in Nepal. *Irrigation and drainage systems.* 2:147-172.
- Messerschmidt, D. A. 1991. Rapid appraisal of community forestry:

- The RA process tools. Inst. of forestry (IOF) project, Technical paper no. TP 91/2, IOF, Pokhara, Nepal.
- Ostrom, E., P. Benjamin and G. Shivakoti. 1992. Institutions, incentives, and irrigation in Nepal. Nepal irrigation Institutions and systems project. Workshop in political theory and policy analysis, Indiana University, Bloomington, USA.
- Paudel, R., K. N. Pandit, K. R. Adhikari, S. M. Shakya, D. N. Yadav and N. R. Joshi. 1993. A report on "Inventory and need assessment of irrigation systems in north-east Tanahun." A Research Report. Irrigation management systems study group, Institute of agriculture and animal sciences, Rampur, Chitwan, Nepal.
- Pradhan, P. 1989. Resource mobilization and management patterns of irrigation organizations in Nepal. 55-68. pp.
- Pradhan, P., G. Khadka, and D. N. Tiwari. 1988. Resource mobilization and organizational support in irrigation system management: Experience from Kularia, Jamara and Rani Kulos of kailali district in irrigation management in Nepal. International Irrigation Management Institute.
- Pradhan, U. 1988. Local resource mobilization and government intervention in hill irrigation systems in Nepal. Ithaca. NY. Cornell University. Water management synthesis project. USA.
- Shrestha, S. P. 1990. "Multi-functional, non-residential irrigation organization: A case study of Kodku irrigation system of Kathmandu valley." in *Irrigation Management in Nepal: Research paper from a national seminar*. IAAS/IIMI/Winrock International, June 4-6, Bharatpur, Nepal.
- Shukla, A., K. P. Gajurel, G. P. Shivakoti, R. Paudel, K. N. Pandit, K. R. Adhikari, T. B. Thapa, S. M. Shakya, D. N. Yadav, N. R. Joshi and A. P. Shrestha. 1993. A report on "Irrigation resource inventory of east Chitwan." Irrigation management systems study group. Institute of agriculture and animal sciences, Rampur, Chitwan, Nepal.
- Water and Energy Commission Planning Unit (WECS). 1991. Irrigation sector review. Report No. 312/190981/1/1. HMG/Nepal.
- Yoder, R. and S. B. Upadhyay. 1987. "Reconnaissance/inventory study of irrigation systems in the Indrawati basin of Nepal" in *Irrigation Management in Nepal: Research paper from a National Seminar*. IAAS/IIMI/Winrock International, June 4-6, Bharatpur, Nepal.

WATER AVAILABLE IN THE KARSTIC REEF LIMESTONE AREA

By : Sunjoto Sun)*

Abstract:

The population of the Island of Java in Indonesia is very dense, event though in the karstic reef limestone area with no perennial dug wells. The very famous karstic area in Java is " Gunung Sewu " it means thousand mountains , because the mountains consist of many small conical limestone hills. This area lies in the southern part of east and central Java. Water available in this area is not enough to provide a minimal water requirement . So in dry season it must be subsided a water from the other region by car , and we need many tankers every day. In the rainy season with the precipitation about 1700 mm/year, the people use water from small lakes called " telagas " wich usually lie in the depression part, of which there are an estimated 288 and only 38 are perennial. In the some places a number of springs provide some additional supplies but usually small springs. Government has developed increasement of capacity of the telagas and built many rain water tanks. Due to the dry season in this region occurs more than 6 months so the dimension of the tanks needed are very big and consequently the cost will higher. In this paper we propose other technic , that are reservoirs sited in the upstream valleys.

1. Description of the region

Gunung Sewu region, a karstic area in a province of Yogyakarta is probably one of the poorest areas in Indonesia . Most of land is barren and rocky and proper cultivation is limited to the valley areas where the soils are reasonably fertile. The population of the area is around 400.000 with an average population density of around 420 /km². The bulk of the population live in small village of around 300 - 1100 people mainly along the coastal belt are very low despite the fact that some of the most fertile land and best water supplies lie in this zone. Limited cultivation of cassava occurs on the small terraces and lamtoro bushes provide cattle fodder. The two mains catagories of land are hills and valleys. The hill area is characterised by thousands of roughly conical hills separated by valleys and basins; it was densely forested. But now, with virtually the whole area deforested, large scale erosion of the top soil and humus has occurred leaving the hills sparsely vegetated and in many areas, no more than rock outcrop. This region is formed by lime stone with the water table very low and the bare of ground surface so the water available is very small. The existing dependence of most of 284.000 population on low quality water from telagas, only 10 percent of which have water in average year, reveals the extent and urgency of the problem. A further statistic which supports this view is that, of the 288.000 population, 199.000 live between 0 and 3 km from any perennial source of water and the remaining 85.000 live more than 3 km from a perennial source.

)* *Gadjah Mada University, Yogyakarta, Indonesia.*

2. Water Demand

The demand for water determines to large extent the level of investment which could be considered as well as which communities should be provided for. Data from various studies conclude that where reasonable supplies are available between 25 lpcd and 45 lpcd. (liter per capita per day) are generally used. Department of Health uses 60 lpcd as supply standard for rural water supplies. As a comparasion the domestic water consumption in urban area in Indonesia is about 125 lpcd and is designed about 200 lpcd in the year 2000.

3. Water Quality

Suspended and floating solids are general problem in the telagas of Gunung Sewu, where wet season levels of suspended solids become very high. The level of suspended solids and algae is generally accepted by local people who have no other water source. The solids in water for domestic consumption are flocculated by mixing with alum.

Colloids are a problem in telagas water but these can be reasonably easily flocculated with alum. During the wet season, open wells quite often suffer from colloidal suspensions of fine earth brought in by the rains. This generally occurs in wells which are not fully sealed where rainwater soaks into the earth thus bringing in fine suspended particles.

Groundwater chemical levels data shows that the levels and types of dissolved limits with the exception of some occurance of iron and magnesium. Some levels of iron (Fe) over 1.0 mg/l have been recorded, although the average level is less than 0.30 mg/l. The WHO and Indonesian limit is 1.0 mg/l. Magnesium levels recorded are in the range 8.3 to 48.1 mg/l which is below the maximum permitted WHO level of 150 mg/l.

Coliform tests were carried out using coli-count disposable samplers and the result of the tests show that the water quality problem from point of view of coliform is high. So the main conclusion are:

- All water in the province appears to carry pollution, most of which is certainly of faesal origin.
- The least polluted sources are the springs and deep wells (tubewells). However even these are not totally safe source.
- The most polluted sources are the caves and telagas in Gunung Sewu.
- Boiling of consumed water appears to be almost universal; as a result the quality of consumed water, although poor at source. should in fact be reasonable safe.

4. Water Sources

a. Hand dug wells

Hand dug wells are the main source of supply in the province provide domestic water for about 80 % of the population. The number of wells in the province is of the order of 400.000. Most of the wells have been used for generations. In the villages the people generally dig their own well. In the region of Gunung Sewu which is formed by karstic area there are not dug wells because the water table is very deep. But in Wonosari the neighbourgh of Gunung Sewu there are some dug wells with the depth more than 35 meters.

b. Springs.

Springs occur where a groundwater aquifer has a surface outlet. The relatively hilly terrain and complex geology around the province result in the occurrence of many thousands of springs. But in Gunung Sewu area there are only some perennial springs with the discharge is very low. The main drawback with springs is that they are frequently located far away from the centres of demand. Springs in this area are usually sited on river valleys we need about 500 m to 3 km to find a water from this source.

c. Telagas

Small lakes called "telagas" occur in the valleys of Gunung Sewu and are sealed by accumulated clay which prevents leakage into the underlying karst. This drainage may be naturally or artificially blocked. Typical telagas occupy between 0.5 and 2.0 ha when full. Apart from providing domestic water, telagas are also vital for watering livestock which are an important form of wealth problem in this area. There are some 250 telagas in this area, of which about 50 are perennial. Telagas are the most important single source of dry season water, and suffer progressively from annual siltation with erosion material washed from the surrounding limestone hills. Storage is often limited by horizontal leakage into limestone fissures which starts once the telagas has filled to a certain level. Even in perennial telagas, water becomes very polluted in the dry season. A telaga will only normally remain perennial if its maximum wet season depth exceeds about four meters.

d. Rain Water Tanks.

The use of household tanks to store rainwater collected from roof runoff is increasing in this area. A number of designs of rainwater tanks have been tried, and clearly the most successful model is a simple 9 m³ ferrocement tank. Tanks made of masonry are very prone to leakage, and large communal tanks, although cheaper per unit volume, have been less successful because of organisational difficulties with rationing the very limited supplies. Some trials using bamboo cement initially appeared very promising and cheap, but recently a number of failures have occurred due to failure of the bamboo. Rainwater tanks are the most costly form of water supply apart from tankers and should be reserved for villages where very severe water supply condition exist and no alternative sources are available even though the quality of water will decrease during dry season which no discharge inflow. From the calculation and experience a roof area of 50 m² is good enough for the 9 m³ tank in this area.

e. Canals and Rivers

Canals and rivers are used extensively for clothes washing and bathing. They are very rarely used for drinking water except when other sources dry up. Where the water is used for drinking the villagers generally dig a pit at the side of a river and collect seepage inflow which should be better quality. In the hills, river water is less polluted than in the plains. Rivers are extensively used for defaecation and thus a very high risk area for many diseases even though direct consumption of the water does not take place. Control will be difficult and could only be achieved by a combined water supply, sanitation and educational program. But in this area there are only 38 perennial rivers of about 288. The ratio of maximum to minimum discharge of the perennial rivers is very big and it means those river are sick.

f. Underground rivers.

An underground water system which traverses from north to south, discharges large dry season flows to sea. Runoff drains in to the biggest system via network of sink holes, of which 264 were identified and surveyed during the 1982 and 1983 cave expeditions. Most of these are not developable as a water supply source without very complex engineering works, the sink holes are often very deep and linked ultimately to the flowing river courses via a system of horizontal caves and vertical shafts. Recently, the discharge of this underground river decreases from year to year, for instance underground river in Bribin cave, had been designed with $2 \text{ m}^3/\text{s}$ in the year 1981, but now is designed only less than $1 \text{ m}^3/\text{s}$.

g. Mobil tankers

In the two months last dry season apart of this area will have annual problem that is a lag of water. There is not alternative of water sources in this area except mobil tankers which bring it from about 25 km distance. So every day, government sends the tankers to this region to provide a water and usually about 40 tankers of 8 m^3 volume per day. This supply system is very expensive but there is not other alternatif. The problem is not only water for the people but we need also for the cattle, cows and buffalos.

5. Small Reservoir

General thinking, the idea to build a dam on the karstic area is imposible. But in this case the dam is not a big dam, but small dam like telaga but sited in the upstream valleys. We have to be sure that the geotechnical condition is good enough, or with certain treatment. Usually the main problem of reservoir on the karstic area is leakage due to the crack, cave or underground river and the treatment on the leakage is necessary. In this case the blanket clay is good enough because the cost will be cheaper than the other technic. There will not have a problem of foundation or material needed because the hardness of lime stones is good enough as a dam material, and dam foundation. The advantage of this dam which sited upper than the area irrigated, and housing, so we do not need pumping station to allow water flow to the downstream. With this irrigation system we hope that vegetation will grow and cover ground surface, and finally reduce runoff and keep rain water as groundwater.

6. Conclusion

Water is main problem in this area, and in dry season some of people spend half day to get a water. Due to much waste time to get a water to support their, the production of life is very low. The lag of water in dry season in this area caused by the soil and rock can not keep rain water as ground water. The existing source or available water is not enough to support the requirement caused by deforestation. So some technic should be applied to create covering of vegetation and consequently to minimize runoff and increase volume of groundwater. In this case, small dam to create a small reservoir is reasonable. Forestation is main aim to develop ideal region which can provide ground water on all season. Due to the problem of land is planted by farmer so forestation program is rather difficult be executed, so the solution is vegetation density should be increased by farmer's plantation as a vegetative covering ground surface and this program have to be supported by enough water so we need small reservoir in the upper valleys. The advantages of

this technic are small possibility of cave which related on underground river compare to the telagas which usually lie in down-stream, then water storage can irrigate bigger area to develop micro climate and finally vegetation will grow and cover this area and consequently the volume of groundwater will increase.

7. Acknowledgement

We want to thank to Sir M Mac Donald & Partners in association with Binnie & Partners Hunting Technical Services due to this paper is summarized from their report "Greater Yogyakarta, Groundwater Resources Study.

References

- Sir M Mac Donald & Partners in association with Binnie & Partners Hunting Technical Services Ltd. 1984, Greater Yogyakarta, Groundwater Resources Study.
- Sunjoto, 1993, Dryness in karstic area and alternatif solution, Proc. Nasional Seminar Inter University Center Engineering Science, Gadjah Mada University, Yogyakarta.

THE PRESENT UTILITY OF RAINFALL IN SOUTH PART OF NINGXIA AND ITS DEVELOPMENT PROSPERT

Yu Junling

*Commission of Agricultural Construction, Ningxia Hui Autonomous Region,
Yinchuan 750001, China*

1. The situation of drought and lack of rainfall and water

Water is the source of all lives. The economic and social development of human beings mainly depended on rainfall. With the rapid increase in population and fast developmend of our economy and society, people are consuming more and more water but there is less clean water which can meet people's demand.

China has a rich water-sources, yet the water possessing of an average person only accounts for 1/4 that of the world,so China is a country lack of water. Situated in North-west of China, Ningxia covers an area of 51,500 kilometers with average anuual precipitation of 15.7 billion cubic meters. If the precipitation volum is considered per unit area, it takes up 1/2 of the country, but 1/16 of the country if the depth of the rainoff is reckoned. With 1 billion cubic meter underground water, the average water possession of each person is 1/12 of that of the country, so Ningxia is also one of the provinces or regions lack of water.

The northern pleteaus of Ningxia are known as the home of fish and rice and can be compared to the southen parts of China since the Yellow River runs through from south to north and irrigates the area while in the southen part of Ningxia of 31.700 kilometers in area, the Liupan mountain has an average rainfall of between 800-900 mm, called as a rainy island and it is an area of semi-humidity, but this area only accounts for 0.5 % of the whole since it is about 1500 kilometers. And semi-arid land of 10. 300 kilometers has the rainfall of between 600- 400 mm, taking up 32.17% of the whole and the arid land of 11,900 kilometers has the rainfall of between 400-200 mm,taking up 62.77%. Also due to the incoincidence of farm-season and rain fall within the year, 70% of the precipitation of 10 billion cubic meters mainly falls in July, August and September and there is only 0.03 billion cubic meter underground water that can be used, but unevenly distributed. Large uncovered areas of land with water and soil losses aggravated shortage of water both in rural and urban areas. Therefor it is a great task for us how to make a good use of water, develop water resources and meet the increasing demand for water by the people.

2. The Preseat Utility of rainfall

To solve the water-deficiency problem in southern Ningxia, the State council, after the establishment of the New China, put the southern Ningxia (including Xiji, Guyuan and Haiyuan area) into the list of special agricultural projects. The government together with the people launched a sweeping development program of utilising rainfall as the key point.

2.1 245 reservoirs small and medium size and 390 dams with capacity of 1 billion cubic meters were established to collect and store rainoff mainly from stormrain and to irrigate the land of 350,000 mu.

2.2 Flat terraced land and ditches of 2.4 million mu with stored water and humidity were cultivated and has the capacity of 200-250 cubic meters per mu if counted as precipitation volume of 400-450 mm.

2.3 A multi-control method was adopted by means of managing mountains, water, fields, trees and roads. 7 watered areas were built up with an area of 1.8575 million mu, taking up 4.6% of soil and water losses area. As a result, no soil moved and no water escaped in this managed land.

2.4 A land of 4.77 million mu was grown trees, an area of 1.21 million mu hills were closed to facilitate afforestation, a land of 5.68 million mu was planted grass and a grassland of 2.01 million mu was improved. All of this increased the vegetation, bettered the ecological environment, conserved the water and soil, alleviated the shortage of energy supply for the farmers and promoted the development of forestry and animal-husbandry.

2.5 0.18 million water cellars were created and the water problems was solved for 0.55 million people and 1.16 million animals.

2.6 Since there is locally more hilly land, more rainstorm, more rainoff after the rain, thicker layer of soil and more sun-heat, the scientific personnels in recent years conducted an experiment on how to collect rainfall at upper part of the mountain and store it by building water cellars at the middle part and cultivate the field land down the mountain by conducting water through pipes and tubes and the experiment resulted in success. Of the 100 water cellars built in Haiyuan, Guyuan and Yongxin counties, a steel-cemented water cellar with capacity of 40 cubic meters requires only 1000 to be constructed and water a land of 2 mu when under the cover of plastic films and dried grass or by injection. Thus melons and vegetables of 1,500 kilograms mu can be obtained with total value of 700-800. If crops are grown, the yield of 400 kilogram mu can be got and will be 10 times as much as that of arid-land in quantity.

2.7 The increase in artificial rain has seen a good result through the years. Particularly after 1990 rain-accelerating substance was applied to layers of cumulus in May and June, which, to some extent, alleviated the drought.

Of the 1 billion cubic-meter precipitation annually in southern Ningxia, the consumption of water by crops, trees, grass and human and animals is of 29 billion cubic meters, 29% of all, the evaporation of 15.7 billion cubic meters takes 57%, the penetration of 1 billion cubic meters makes up 10% and water losses of 0.4 billion cubic meters accounts for 4%. Therefore there is a great potential for utility of water when well controlled.

3. The prospect of rainfall utility

3.1 Two things can be done to make a full use of rainfall

3.1.1 To upgrade the utility rate of the rain-water. To fully collect the runoff from the snow and rain. Of 0.4 billion cubic-meter water losses, there is only 0.14 cubic meter water which has been collected and stored while other 0.26 cubic-meter water runs to other areas. Then 58% of the reservoirs which are collapsing can't hold water at flood season nor can it store after the flood. Therefore it is proposed that water-collecting facilities of small size be set up at the upper part of the reservoirs to save water individually for later use. To store water underground to control evaporation by erecting water-cellars. In the southern mountainous areas of Ningxia, the land is bald and covered with no vegetation, so there is a quick evaporation of rainfall (the annual evaporation is between 1320-2700 mm). A research unit decided that 60 mm water collected and stored from the runoff (about 39.6 m³/mu) can solve the irrigation problem. The local experience is that the summer crops when watered properly three times, each with water of 10 cubic meters will see a good harvest. Even in the drought year, there is at least yearly 190 mm precipitation, mainly in the form of torrents in July, August and September. Thus no matter whether there is sufficient rainfall or not, half of the rain falls from the runoff can be collected and each mu can store water of more than 50 cubic meter. Moreover, there is low density of population here. Each person averagely possesses dozens of mu and cultivate a land of about 10 mu. So there is large area for water-collecting. a. To stop the evaporation and speed up water-accumulation, penetrating-resistance technique can be adopted. For instance when water-cellars are constructed underground, water can be conveyed through tubes and pipes and drip irrigation system used. b. To grow trees and grass constantly to improve the ecology and keep the humidity of the soil and water.

According to some experts in the rainfall area of 400-450 mm, a land of one mu

of trees and grass can yearly save water of 250-300 cubic meters.

3.1.2 To increase the transformation rate

In most parts of southern Ningxia, the agricultural technique is backward and cultivation is extensive. A crop yield of 0.2-0.3 kg/mm can be obtained in the dry-crop area, a yield of 0.05-0.1 kg/mm in the fields reliable on the weather, but the crop-yield of 0.5-0.6 kg and 0.2-0.35 kg/mm respectively can be achieved in the fields of the scientific test centers which are scientifically and comprehensively managed. So the efficiency was increased by twice or even more. It's noted that a scientific, comprehensive and supplementary investment should be carried out in agriculture before the transformation rate of precipitation is increased.

In the irrigated areas, the old method of flood irrigating land should be changed and water-saving method be extended. For instance, a land per mu will require annually a water of 350-600 cubic meters when flood-irrigated, but it will only need a water of 50-60 m³ when drip-irrigated.

3.2 To do well at artificial-rain.

Besides the artificial-rain-increasing method applied to the layers of cumulus congestus, the artificial rain by convect cumulus congestus should be promoted and applied. After the implementation of the water-saving facilities, the duration of artificial rain can be prolonged to mid-autumn to increase the volume of the saved-water.

4. To upgrade the senses of rain-water utility.

9/10 of the cultivated land in southern Ningxia is of dry-crop agriculture and it is true of 2/3 of the cultivated land in China. Also the dry-crop agriculture and arid and semi-arid land areas take up a percentage large in many parts of the world.

If per unit area yield of dry-crops is intended to be enhanced, water should be increased to irrigate the land. Otherwise the crops can't get enough nutrition. There are three ways to increase the water: One is to dig water-wells to extract water from the underground. Another is to transfer water from other places; Then another is to make a good use of rain or snow through a scientific method. However the two previous options have much restriction since the transfer of water and its construction are very costly, energy-consuming and low efficient. So only water-saving cellars have great advantages. a. It can be done at any place where snow and rain are available. b. It is easy for every family to construct or build it when they are told how to. c. It is inexpensive short-time consuming and

has a quick benefit. d. It can adjust the unbalance of rainfall during the raining season so as to guarantee a good harvest no matter it is a drought or flood. e. It can prevent the losses of water and soil and improve the ecological environment. f. The farmers can locally build their homes, develop the green enterprises and eliminate the poverty. g. There is no risk but a great success. h. It can create a better environment for the adjustment of agriculture structure and for the overall development of agriculture, forestry, animal-husbandry and other services.

To extend the water-collecting and water saving method, it has a great economic, social and ecological importance for the agriculture development in dry-crops areas and for the growing demand for by products.

Figuratively speaking to scientifically collect and utilize rainfall in arid land area is just to obtain grain, edible oil, silver and gold. But so far since people have little understanding of this, we should propagate and extend the above eight advantages of such water-saving irrigation method.

Therefore Ningxia will make great efforts in the next 7 years of the century to help the 2 million people in the area get rid of poverty and live a happy life!

RAINWATER HARVESTING AND STORAGE TECHNIQUES FROM BANGLADESH

Dr. Abutaher Md. Ziauddin
Professor
Department of Farm Power & Machinery
Bangladesh Agricultural University
Mymensingh 2202, Bangladesh

ABSTRACT

It seems a cruel irony that a country with so much rainfall has to resort so often to contaminated surface water for cooking and drinking. There are ways to harvest the clean rainwater, and to store it for use during the dry season, as many Bangladeshis are already doing in a very traditional way. A study was undertaken to investigate the rainwater harvesting and storage techniques of coastal villages of Bangladesh. It concluded that the proper collection and storage of rainwater could solve the drinking water problem where there is a serious shortage.

INTRODUCTION

Even though Bangladesh has a very high rainfall from April to October, much of the water harvested and consumed, especially in the rural areas, is contaminated. About 85 percent of the total population of the country have no access to clean drinking water and adequate sanitation facilities. The problem is very serious in the southern coastal area (where 18 percent of the population live), as both surface and ground water are very saline. The problem intensifies during the dry season and during floods. Although people living in coastal and hilly Bangladesh have been collecting and using rainwater since time immemorial, no specific study

on rainwater use in the region was available. An investigation was therefore conducted into the socioeconomic aspects of, and the scope for the development of, the rainwater catchment facilities in the country. A case study was conducted in twelve different villages of the Dacope Thana of Khulna district in Bangladesh during the months of October and November. The objectives of the study were:

1. To study the present systems of rainwater use and storage.
2. To study the socio-cultural and economic aspects of water use of both rainwater and other locally available sources.
3. To perform a comparative cost analysis between rainwater use and the use of water from other available sources.

METHODOLOGY

The study considered the general condition of rainwater catchment system, storage practices, water quality control methods. In general, the inhabitants of Dacope Thana use water from ponds, canals or ditches, rivers, tubewells, the DPHE-UNICEF sand-filter facilities, and rainwater. After a series of discussions with a sociologist, an engineer and an economist, an appropriate questionnaire was prepared to collect primary data. The villages in the study area usually consist of two or three *paras*. A *para* is a local name for a distinct cluster of households within a village. A sampling unit, in this case a single farm household, was selected randomly from each *para* to produce the study sample. Finally, within each selected household, the family leader was chosen to be the interviewee. Key individuals included in the interviews were the village school teacher, members of village committees, common labourers, and different

categories of farmers and non-farmers. A total of 36 farm households were interviewed from 12 different selected villages. The data were carefully compiled and analysed to produce the study results.

RESULTS AND DISCUSSIONS

Table 1 shows the condition of drinking water facilities in the twelve villages in Dacope. About 49 percent of tubewells were found to be out of order, and of those working, 41 percent were not in use because their water was saline. Of the DPHE-UNICEF sand-filtered facilities, 45 percent were found to be idle. Only a few of the ponds were government-owned, most being private. A joint programme by the Department of Public Health (DPHE) and UNICEF in the area had been working to provide better quality drinking water. This programme included the establishment of a sand-filtered tank of 2m X 2m X 2m. A handpump pumped water from a pond (as the ground water was too salty) to the tank, where it was filtered. Even with this filtering, during the dry season the water became salty and people did not want to use it.

Women played a significant role in the collection of drinking water. It was assumed that water collection was a woman's job only, and men would do it only under exceptional circumstances. Sometimes the women had to walk very far to collect water in *kalshi* (earthen water containers made by local artisans).

Present Status of Rainwater Use

People used rainwater for drinking, cooking, bathing, and washing clothes. It was

reported that vegetables, pulses, and rice cooked in rainwater tasted better. Several users felt that it was not healthy to drink only rainwater, because it did not contain minerals, as groundwater did, but some drank it whenever they could because they preferred the taste. Figure 1 shows that during the rainy season 35.5 percent of households prefer rainwater, while during the dry season this dropped to 2.4 percent, and ponds or tubewells were used. This indicated that the people could use rainwater in dry season if it was available in a storage. During the rainy season the villagers harvested the water and stored it, sometimes enough for the whole year, but more often only for a few months.

Methods of rainwater harvest and storage

The method of harvesting the rainwater varied, depending on the kind of house the villager lived in (Table 2). There were three common types of roof in the area: corrugated iron sheets, tiles, and thatch. Roof discharge was a common method of rainwater collection. Gutters made of corrugated iron sheet, bamboo, betel-nut tree and the bark of banana plant had been widely used in the rainwater catchment systems (Fig. 2). People with thatched houses usually used other devices to collect rainwater from the open sky, such as an upturned umbrella or a polythene sheet, a mosquito net, or a clean *sari*. The water collected in these ways were emptied into a *kalshi*, and these in turn were emptied into *motkas*, larger earthen storage vessels. The capacity of storage ranged from 32 to 5376 litres. *Motkas* and *kalshis* were the only popular rainwater storage facilities available in the area. *Motkas* were usually used by rich people for long-term storage. These were semi-permanently placed inside or outside the house. The quality of the stored water varied, depending on the motivation and education of the households.

Some people did realize the benefits of drinking pure water though, and Table 3 shows the different sources used in the villages. It reveals the fact that during rainy season people drink rain water significantly. Only 13.47 percent of households in the Sutarkhali village consume rainwater even in the dry season by storing rainwater. Two households living in Sutarkhali village were so enthusiastic that they stored rainwater in large *motkas* for yearround consumption. They took water out with a small pre-cleaned pot, and kept the *motka* closed all the time (Fig. 3).

Quality of rainwater

Most households with limited storage capacity found it very difficult to maintain quality, as mosquito larvae and other insects developed within two weeks in the stored rainwater. Certain common varieties of fish, known locally as *lot* (*Anabas Testudineus*), *sing* (*Heteropneustes Fossils*), or *magur* (*Clarias Batracus*) were introduced into the stored water to eat the larvae of mosquito and other similar insects, but the fish discharge their own excreta in the water, which again reduces the quality of the drinking water. Sometimes people found frogs, toads, and the dead bodies of rodents, lizards, cockroaches etc. in the stored rainwater. This was caused by improper storage practices.

An effective technique to maintain the quality of the stored water by treating it, using locally available material, was practised by two households. They stacked snail shells in several layers, and in between the layers, cowdung, straw, or rice husk were placed. Rice husk was spread over the layers and the stack was burned gradually. The burnt shell was collected and added to the stored

water at least once a month. It is believed that the calcium (lime) or its compound in the burnt shell is the main element which purifies the water. Some consumers drink rainwater after simply filtering it. Few families treated water using known chemicals such as alum, lime or water-purifying tablets.

Future of rainwater use and storage

About 75 percent of the villagers wanted to build better and larger rainwater storage units for private use. But only economically solvent households having more than five acres of land were able to do this independently. Farmers possessing less than an acre of land preferred building of a common drinking water storage facility for community use. Most of the user's assumed that it is the responsibility of the government to provide pure water for them. Only a few households were willing to take out a bank loan at low interest rates to build the storage facility, if the bank loan process be simplified.

Cost analysis of the different types of water sources were also carried out. The cost was calculated on the basis of a consumption rate of three litres per person per day for a family of seven. The cost analysis of the drinking water storage facility included the labour cost of collection, maintenance costs, and the installation costs. The rainwater catchment system was found to be slightly cheaper than the sand-filtered system (Table 4)

The study concluded that the proper collection and storage of rainwater could solve the drinking water problem where there is a serious shortage.

ACKNOWLEDGEMENTS

The author gratefully acknowledge the full financial support from the International Development Research Centre, Canada which made the study possible.

REFERENCES

1. DPHE 1986 Annual Report of the Department of Public Health Engineering, Dacope Upozilla. Dacope, Khulna, Bangladesh.
2. Statistical Year Book of Bangladesh, 1983. Ministry of Planning, Government of Bangladesh, Dhaka
3. Talukder, M.S.C. 1982. Estimation of some agro-climatological parameters from standard meteorological observations in Bangladesh. Physics Department, The Royal Veterinary and Agricultural University, Copenhagen.
4. Hussain, M.D., A.T.M. Maududdin and R. Ali. 1988 Rainwater use in Bangladesh -- a case study in Dacope Upozilla. Research Report No. 3 Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Table 1. Present Situation of Drinking Water Facilities in the Villages of Dacope

Name of Village	Hand tubewells					DPHE-UNICEF facilities			Pond ownership	
	Total no.	No. out of order	good working condition			Total no.	No. in good working condition	No. unused	No. of public pond	No. of private pond
			No. used	No. unused due to salinity	Total					
Sutarkhali	3	3	2	3	5	2	2	--	3	3
Anandnagar	4	2	2	--	2	--	--	--	--	--
Satgharia	--	--	--	--	--	--	--	--	--	--
Khatai	4	2	2	--	2	2	1	--	--	1
Khona	3	1	--	2	2	1	--	1	1	1
Barukhali	4	3	1	--	1	2	1	1	--	2
Chunkuri	13	9	3	1	3	1	--	1	3	3
Baccunia	1	1	--	--	--	--	--	--	--	--
Sanedersad	3	2	--	1	1	--	--	--	--	1
Srinagar	3	2	--	1	1	1	1	--	--	2
Ramnagar	3	1	1	1	2	--	--	--	1	1
Buriroba	2	--	--	2	2	--	--	--	--	2
Total	53	28	16	11	27	9	5	4	5	20

Source: Office of Sub-Assistant Engineer, Public Health, Government of Bangladesh, Dacope, Khulna, 1986

Table 2 Rainwater Collection and Storage Scenario in Dacobe, Khuina

Number of households	Total rainwater storage capacity for drinking purposes only		Type and number of storage facilities (type - number)	Method of rainwater collection (type)
	For rainy season use (litre)	For off-season use (litre)		
6	90	--	A - 5	I
9	--	5376	{ D - 4 C - 8	I
6	--	4224	D - 6	I
5	36	--	A - 5	I
6	64	--	A - 4	I
22	640	--	C - 2	I
6	192	--	{ B - 1 A - 5	I
5	126	--	{ B - 1 A - 1	V
12	576	--	{ C - 1 B - 2	I
5	123	--	{ B - 1 A - 1	IV
5	32	--	A - 3	II
16	360	--	C - 3	I
7	288	--	{ B - 2 A - 3	III
6	724	--	{ C - 2 A - 4	I
20	384	--	{ B - 3 A - 2	V
9	--	1280	{ C - 4 A - 2	I
7	80	--	A - 5	II

Storage facilities:

Type A - a *Kaishi* of 16 litres
 Type B - a *Motka* of 120 litres
 Type C - a *Motka* of 350 litres
 Type D - a *Motka* of 750 litres

Method of rainwater collection:

Type I - roof discharge through CI sheet
 Type II - roof discharge through tiles
 Type III - roof discharge through straw
 Type IV - polythene paper under open sky
 Type V - bedsheet/*sari* under open sky

Table 3 Percentage of Households Using Different Sources of Drinking Water in Dacope, Khuina

Village	Water source											
	Pond		River		Canal/ditch		Rainwater		Hand tubewell		DPHE-UNICEF Sand filter	
	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Sutarkhali	--	20	--	--	--	--	40	13.47	--	6.6	6.6	13.33
Anandanagar	25	25	--	--	--	--	--	--	25	25	--	--
Satgoria	--	--	--	--	--	--	--	--	50	50	--	--
Khatali	--	--	--	--	--	--	14	--	--	28	29	29
Khona	10	9	6	--	16	16	26	--	--	16	--	--
Barokhali	--	14	--	--	--	--	--	--	14	14	29	29
Chunkuri	14	14	--	--	--	--	14	--	29	29	--	--
Batbunia	25	25	25	25	--	--	--	--	--	--	--	--
Shaneparaad	11	23	17	22	--	--	22	--	--	--	--	--
Srinagar	11	10	--	--	--	--	23	--	11	11	11	23
Ramnagar	--	20	--	--	--	--	40	--	20	20	--	--
Burirdoba	16.5	16.5	--	--	--	--	34	--	16.5	16.5	--	--

Note : October to April is considered to be the dry season.

Table 4 Comparative Cost of Different Types of Water Sources in Dacope, Khuina

Types of water source	Average water cost (Tk/litre)	Remarks
1. Pond	0.254	Highly Contaminated
2. River	0.045	Highly Contaminated
3. Canal/Ditch	0.045	Highly Contaminated
4. Rainwater :		
a. Roof discharge	0.290	Safe, if harvested properly but lack of natural minerals
b. Open sky catchment	0.300	
5. Hand tubewell	0.285	Highly Saline
6. DPHE-UNICEF sand filtered facility	0.321	Saline

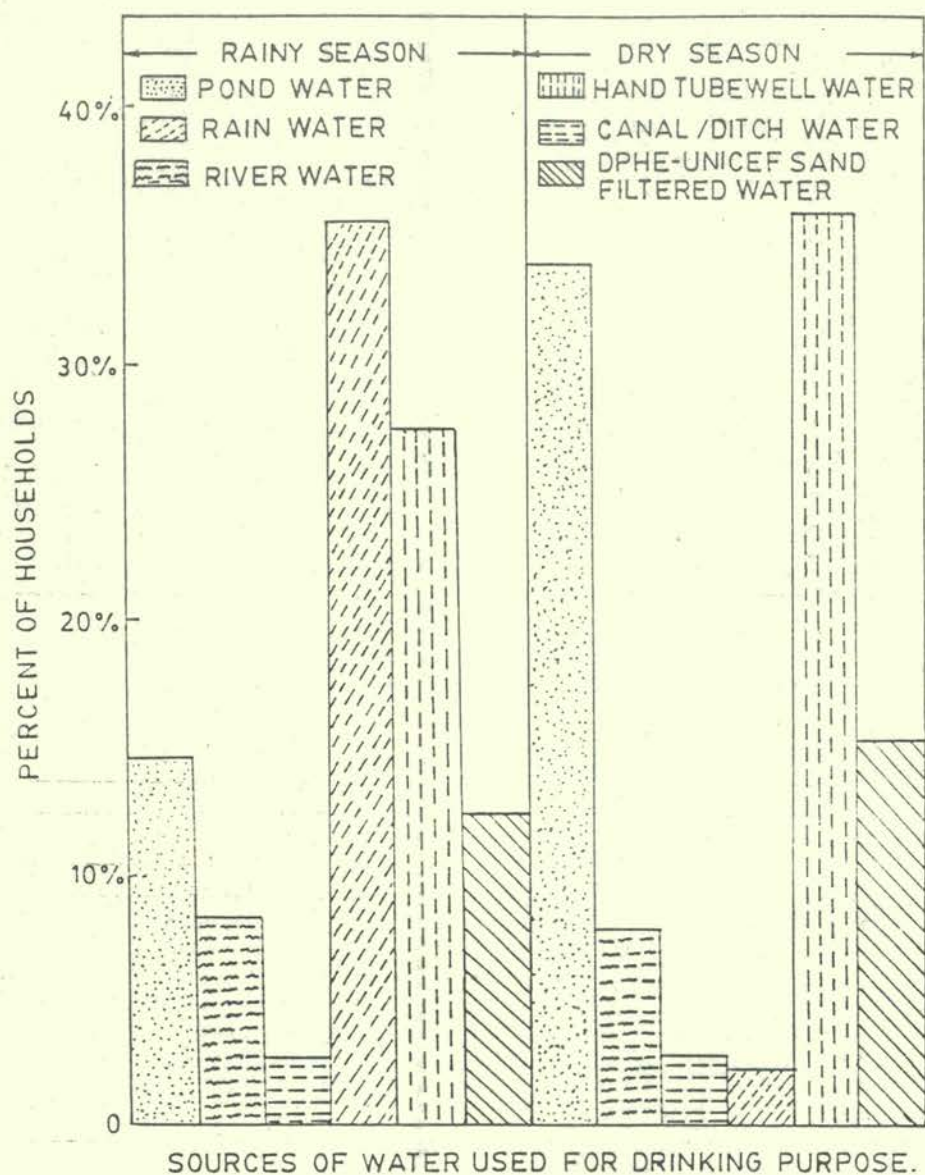


FIG. 1 CONSUMPTION OF DRINKING WATER BY HOUSEHOLDS IN DIFFERENT SEASONS.

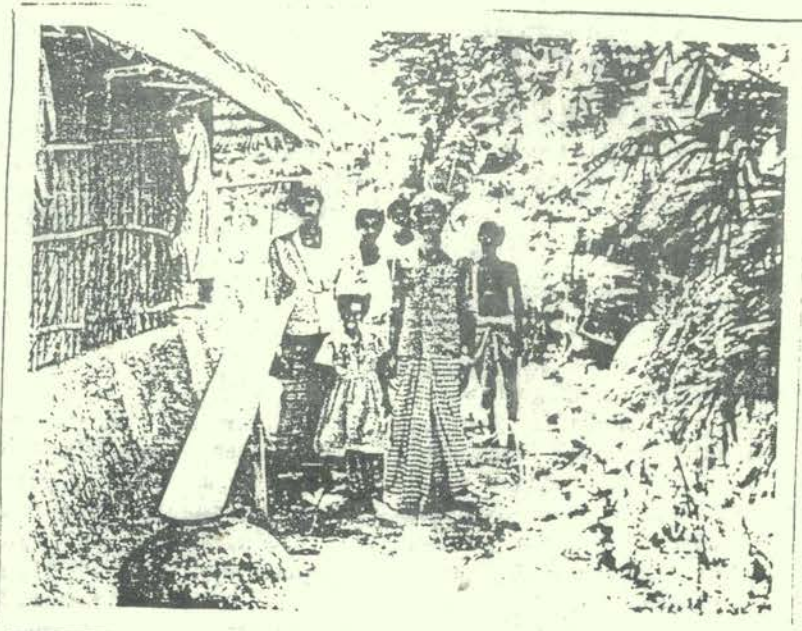


Fig 2 Rainwater collection through roof discharge using a gutter made of C.I. sheet

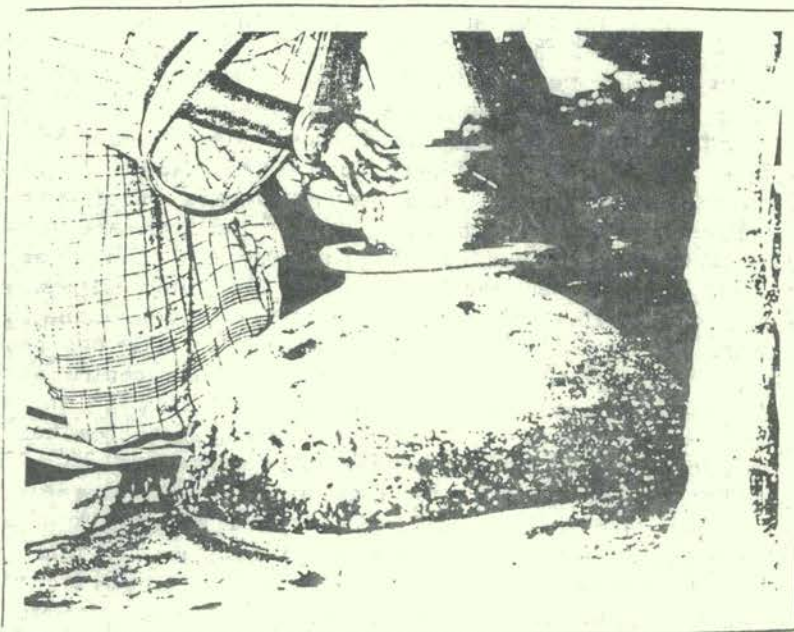


Fig 3 A "Motka", a popular rainwater storage device in Bangladesh

Exploitation and Utilization of Rainwater Resources on Arid Area

Tian Yuan
Department of Hydraulic and
Electric Engineering, Gansu
Agricultural University
Lanzhou, Gansu P.R.China
730070

Su Yongxin
Flood-Control Headquarters
Office in Gansu Province
Lanzhou, Gansu P.R.China 730000

ABSTRACT

China is one of 40 serious poor water country in the world. Gansu province is extreme arid area in china. Arid and poor water is confine element for development of industry and agriculture, and influence people's life in this area. Most area of Gansu province rains between 200mm--450mm. According to hydrology station observe, per year in yearly rainwater 450mm place, waste rainwater are 220mm It is too pity to arid area. Since 1988, under the leadership of water conservancy bureau of Gansu province, people began to utilize rainwater resources for people and animal and irrigation farmland. The utilization of rainwater obtains many experience and good result. It is good way the utilization of rainwater in arid area.

1. INTRODUCTION

Gansu province is located in centre region in china, the southeast is very far from ocean, the north west is very near to "the highest place in the world". It specially places the north east side apart from the whole Qinghai-Xizang plateau and the north side of the Qin-Ling mountain. Objective takes shape a poor rainwater amount and dry climate. The area of north west 5 provinces are one third in whole china, but it is only one tenth the water resources of the earth's surface. Particularly Gansu is famous poor water in china. Many year average runoff by itself is 29900 million cubic metres, addition comes from foreign area, total is 60300 million cubic meters. Average runoff per people is 1513 cubic metres, average in china is 2539 cubic metres, average in the world is 10413 cubic metres. The runoff by itself is less than other in the Gansu centre area, average per people has only 257 cubic metres. Average water per ha has only 10180 cubic metres, average per ha in china is 25040 cubic metres, therefore, Gansu's water is less than other area per people and per ha averagely. With reference to the district of Gansu centre and He-Xi district yearly rainwater are less than 250mm. According to the United Nations ESCO divides target. It is exceedingly dry area. This area has 53% in Gansu. Other area in Gansu province is yearly rainwater among 250--450mm, it is dry region. Whether exceedingly dry area or dry region, really partly rainwater takes shape surface's runoff and loss of water and erosion of soil, the other permeated the soil and evaporated consume, to this area of poor water resources suffers heavy losses. According to hydrology station report: in the centre district average runoff depth 20--30mm rainwater waste for nothing, i.e. 195--300 cubic metres rainwater is lost every year per ha. In

yearly rainwater is 450mm place(down Lanzhou the Yellow River), the efficacy rainwater is 315mm except loss has 290mm and minus one third evaporation water (according to experiment, evaporation of crop are (50-60)% irrigation quota). The water of evaporation and permeation for nothing is approximately 200mm, addition earth's surface runoff loss, total loss water for nothing are approximately 220mm per year. i.e.2175 cubic metres is lost per ha. It is a pity in the dry district. How use rainwater resources, to solve water for the people and domestic animal and develop saving irrigation field, is important problem in the dry area.

2.CHARACTERISTICS OF RAINFALL RESOURCES

Since 1988, the Water Conservancy Bureau of Gansu Province set up experiment group for rainwater utilization in dry district. They set up 7 experiment station in Tong Wei, Yu Zhong, Ding Xi, Hui Ning, Jing Yuan and Xi Feng, 29 compare experiment plot, 6 experiment station make using natural rainwater observation. Xi Feng station makes using artificial rainwater device. The content of observations are mainly measuring natural rainwater and flow. The measure of flow has been used by volume's method or water watch. Slope preventing permeatal material have concrete, plastic film (covering sand or glass soil for protection), 3:7 orthod, rammed genetic soil, cement tile, machine tile and green tile (for roof house). Experiment ground is rectangle. Slope is 1/60--1/9, the slope of house-roof is 1/4--1/3. The device of retention basin are water cellar or concrete pool. Through experiment and demostration, the resources of rainwater have as follow characteristics.

2.1 Rainwater Characteristics in Dry Area From the characteristics of rainwater, the rainwater appear in the form of shower and torrential rain in the dry area. Through the data stasistical analyse by hydrology station to 1971--1991 year ten meteorological station over year rainwater 300mm district, over 50mm per day, average per year has once at least. On the condition of the rainwater, if people did not make rational use of water resources in the district of environment of ecolog turns into worse.

2.2 Relationship between the the Efficiency of Collecting Runoff and the Characteristic of Rainwater, Preventing Permeation Material According to every experiment station observe data, obtain the relationship between the efficiency of collecting runoff and the characteristic of rainwater using concrete, plastic film covering sand, rammed genetic soil, 3:7 orthod, common tile, cement tile and so on, different material prevent permeation, selecting Jin-Yuan and Guo-Chang two hydrology station, to yearly rainwater 190mm and 374mm typical year making analyse. The result of calculation are shown in table 1. According to the table 1 obtain, the efficiency of collecting runoff are fastly increased while every rainwater and the intensity of rainwater are increased. Under the year of rainwater 190mm, every rainwater is less than 10mm 84% and 62% in the whole year, therefore are lower the efficiency of collecting rainwater; under the year of rainwater 374mm, every rainwater less than 10mm is 69% and 31% in the whole year, therefore are higher the

efficiency of collecting runoff, particularly soil for preventing permeation are better this increase of the efficiency.

Table 1 Every preventing permeation from typical year efficiency for collecting rainwater calculation result

typical year	(4-10) month rainwater characteristics				(6)	(7)	(8)	(9)	(10)	(11)
	(2)	(3)	(4)	(5)						
Jin Yuan in 1965 190mm	<5	15	27.3	14.5	0.6	0	0.02	0	0.18	0.64
	10	12	89.6	47.4	0.76	0.21	0.17	0.11	0.46	0.76
	20	4	49.4	26.1	0.8	0.41	0.26	0.17	0.53	0.78
	30	1	22.7	12	0.83	0.58	0.34	0.25	0.61	0.8
	total	32	189	100	0.76	0.27	0.19	0.12	0.46	0.75
Hui Nin in 1963 374mm	<5	11	22.4	7.2	0.64	0	0.07	0.01	0.24	0.7
	10	11	73.6	23.5	0.75	0.41	0.13	0.08	0.43	0.74
	20	7	95	30.3	0.8	0.42	0.25	0.17	0.54	0.77
	30	1	28.9	9.2	0.84	0.62	0.35	0.25	0.63	0.79
	>30	2	93.3	29	0.88	0.78	0.54	0.34	0.7	0.87
	total	32	313	100	0.8	0.45	0.3	0.2	0.55	0.79

Note:

- (2) every rainwater grade (mm);
- (3) number of times (times);
- (4) rainwater (mm);
- (5) percentage in whole year (%);
- (6) concrete in Xi Feng district;
- (7) plastic film covering sand in Xi Feng district;
- (8) rammed the soil in Xi Feng district;
- (9) 3:7 plastered soil in Tong Wei district;
- (10) common machine tile in Yu Zhong district;
- (11) cement machine tile in Yu Zhong district.

2.3 Relationship between the Efficiency of Catching Rainwater and Lower Berth Material

According to table 1, the most efficiency material are concrete and cement machine tile in every prevent permeate advice. The material are lower in rate of absorb water, slower in permeate water speed and less in permeate coefficient. Under small rainwater and intensity of rain can give runoff. Under different rainwater of whole year collecting rainwater efficiency is differ very small. Efficiency remains stable, over 70%, but soil material prevent permeation in general result is bad, under 30%, according to year rainwater is differ, year efficiency is very differ. For example rammed genetic soil, when year rainwater is 190mm, year efficiency of collecting rainwater is only 19%, but when year rainwater is 370mm, year efficiency of collecting rainwater is 30%, two things differ 11%.

2.4 Effect of Collecting

Rainwater Slope to Efficiency That earth's surface is sloper may reduce water current thickness in process of rainwater and detention water after stoping rain, therefore, the efficiency of collecting rainwater is higher.

Collecting rainwater area slope is 1/50 in Yu Zhong, concrete field collecting rainwater is only (40-50)%, but experiment field in Xi Feng slope is 1/9, collecting rainwater efficiency is (68-80). In generally speaking, collecting field is not small than 1/10.

2.5 Specific Character of Several Prevent Permeate Modus

According to above different prevent permeate modus collecting rainwater efficiency, by yearly rainwater volume 300mm is standards, consult in 1994 water conservancy project quota, and calculate different seepage prevention material price consider on water delivery, storage and management loss, different seepage prevention scheme calculate efficiency by table 2 must multiplier 0.8.

Table 2 Different Seepage Prevention Characteristic

item	(1)	(2)	(3)	(4)	(5)	(6)
[1]	0.63	0.32	0.63	0.41	0.14	0.22
[2]	0.189	0.096	0.189	0.123	0.042	0.06
[3]	4.7	4.0	4.4	4.8	3.2	1.4
[4]	24.7	41.3	23.5	39	77.2	12.2

Note:

- (1) concrete;
- (2) plastic film covering;
- (3) cement tile;
- (4) machine tile;
- (5) 3:7 spodosols;
- (6) rammed genetic soil.
- [1] calculate collecting runoff efficiency;
- [2] collecting runoff capacity per square meter (yuan);
- [3] price per square meter (yuan);
- [4] collecting runoff price per square meter.

From table 2, the price per square meter in cement tile, concrete and rammed genetic soil collecting runoff is lower, but rammed genetic soil experiment only over one year, has been happened scour, the life estimate about three year, but concrete and cement tile is lasting long. For solve people and domestic animals, cement tile have priority been developed.

3. RAINWATER RESOURCES DEVELOPMENT AND UTILIZATION

In the dry region average per year obtain 250mm--450mm for rainwater. Except water resources lack, soil resources is relative rich, very favourable unite use for rainwater and irrigation. In the dry region has no irrigation, only rainwater sometimes people and domestic animals is very difficulty to drink, impossible irrigation field. Fully utilization rainwater resources have very important sense in this region. Gansu province in recent years use mainly rainwater solving people and domestic animals and partly field irrigation.

3.1 Saving Rainwater for People and Domestic Animals

3.1.1 Rainwater Demand

Collecting rainwater unit for one family, average every family is about five people. Every people per day water consumption include average domestic

animals is 15 litres. Every yearly rainy season consider utilization existing natural collting rainwater and water cellar, solving four month water, other eight month per family require collting rainwater 18 cubic metres.

3.1.2 Rainwater Catchment

First, rainwater catchment for roofing has been fully used, per family house area has been calculated in 40 cubic metres, not enough rainwater, it has been solved by building concrete field.

3.1.3 Price

The price is limit factor for devolping rainwater catchment field. People are no rich in dry region, high price sometime can't bear. Only consider material and sand, stone price, through analyse and calculate, concrete rainwater catchment field per square meter price is 4.7 yuan. Cement tile is 4.4 yuan. When rainwater is different price is also different, result of calculation are schown in the table 3.

Table 3 Different Year Rainwater Region Rainwater Catchment Field Price

						Note:
(1)	(2)	(3)	(4)	(5)	(6)	(1)yearly rainwater (mm); (2)rainwater catchment per squire meter (sq.m);
400	0.24	9.6	35	288	16	(3)house roofing 40 sq.m rainwater catchment; (4)require concrete rainwater catchment field (sq.m);
300	0.18	7.2	60	386	21.5	(5)price per family (yuan);
200	0.12	4.8	110	584	32.4	(6)rainwater catchment price per cubic metre (yuan).

In the table 3 analysed and calculated price compare with supplied water by truck are very cheap, therefore, if state can invest part, and peasant can invest to rely on one's own efforts, thus can solve fund for rainwater catchment field problem.

3.2 Develop Partly Irrigation Agriculture

3.2.1 Adopt advanced irrigation technology, fully used rainwater irrigation field, low-yield dry farm change into water farm. According to Gansu province in the last few year spread drip irrigation technology,irrigation water per ha once 65 cubic metres plant melons, vegetables or fruit tree, per ha in 8 times, yearly ?water demand 600 cubic metres, to yearly rainwater 400mm area, set up one ha drip irrigation, about require concrete rainwater catchment field is 2410 squire metres,i.e.1/4 ha rainwater catchment field obtain one ha drip irrigation. Per massif ration one storage pond of 30 cubic metres. Whole equipment and rainwater catchment field price are about 13500 yuan per ha.

Gansu province partly irrigation project price has high to about 15000 yuan per ha, this shows, in dry region invest about 13500 yuan seting up one ha water field may receive. For example in 1989 Long Xi county An-Tong village Ma-He-Cun has 20 ha lands for planting corn, using rainwater catchment irrigation is only 150 cubic metres, corn yield per ha is 6000 kg, it is more 3000 kg per ha than dry farm.

3.2.2 Rainwater catchment irrigation combine besser with terrace,i.e. partly field rainwater catchment,below seting up water cellar, special irrigation next terrace, this project simple and feasible, the masses is fond of acceptance.

4.CONCLUSION

To sum up, it is feasible to use artificial seepage prevention rainwater

catchment field and rainwater catchment system, solving Gansu province in dry region people and domestic animals and developing irrigation farm technology. It is very worth on spread and used. Using rainwater resources, it may prevent soil and water loss, it owns water and soil resources is about 1% in whole resources to resources and ecosystem no has bad function, fit many dry region, it may solve this region economy developed condition factor--poor water problem, and technology is simple, it is easy by the masses acceptance. This is a small water conservancy project in dry region and investment is no more, but benefit is very good.

REFERENCE

- [1] Luo Mingyue. Gansu province in dry region water resources development and utilization problem: Hydraulic and Electric Technology in Gansu Province, 1988.3 p1--7
- [2] Duo Yuqing, water catchment, preserve in the soil irrigation method, Irrigation and Drainage, 1983.4 p42--46

Development on Rainfed Agriculture of Delta of Wide Area in Asia

by Isao Minami*, Ichiro Kita**, Nobuo Kanamori***,

Chizuko Fukami*, Vuong Bach Tuyet****,

and Saiful Rochdyant*****

Abstract

In Asia there are many big deltas, for example, the Mekong Delta of Vietnam, the Chao Praya Delta of Thailand, a Delta in Indonesia located near the equator line and the Chikugo Delta of Japan in the temperate zone. These deltas have great possibilities of efficient rainfed agriculture if modern integrated rainwater catchment system is introduced to them. In order to check the characteristics of deltas in Asia, we selected three groups of deltas, Mekong Delta, Chao Praya Delta and a Delta in Indonesia and Chikugo Delta as comparative models of deltas in Asia.

Generally, a lot of paddy rice is produced on these deltas. In the torrid zone an ideal project for rainfed paddy rice field will be required on each of these deltas if we are to introduce new rainwater catchment systems with salinity control facilities. Chikugo Delta which is in the temperate zone is under reconstruction of water use system, implemented by the government, including sea water control facility and refinement of rainwater catchment system. Rainwater is utilized together with irrigation water from rivers and reservoirs.

The most difficult problem confronting the introduction of a perfect rainfed agricultural system on a delta is the control of salinity. Fortunately the following beneficial techniques are available: the floating automatic tide gate (FATG) can prevent salt water intrusion and the mini-navigation lock (M-NL) can allow the passage of small boats through the gate.

So far, though rainwater from roofs have been used for drinking, the small scale development by Tameikes is also a recommendable idea for rainwater catchment systems in Asia. In this report, we would like to recommend big rainwater catchment system for deltas with wide area.

*Japan-IRCSA(Japan) **Agri. College of Ishikawa Prefecture(Japan)

***National Land Agency, Government of Japan (Japan)

****Pedagogical Univ. of Tech. (Vietnam)

*****Gajamada Univ. (Indonesia)

1 Climatic conditions of rice producing Deltas in Asia

The climatic patterns among three groups of deltas are compared; Mekong Delta and

Chao Praya Delta in the monsoon, the Delta of Indonesia on latitude 0° of the equator and Chikugo Delta of Japan in the temperate climate. These climatic conditions are skillfully utilized in paddy rice production introducing special water use techniques in these deltas.

The Mekong and Chao Praya Deltas are located in Southeast Asia. There are two seasonal rainfall distribution, rainy season and dry season, in a year. This climatic pattern is called the monsoon type. Fig.1 shows the annual distributions of 5-day rainfall and 5-day averaged temperature, which were deduced from 30 years of continuous daily data.

The Delta in Indonesia lies on the equator line. Rainwater is distributed year round as shown in Fig.1. The temperature is warm and nearly constant through out the year. Rainwater distribution here is different from Mekong and Chao Praya Deltas.

Chikugo Delta exists in East Asia. The climate of the Chikugo Delta consists of warm summer and cool winter. Fig.1 shows that there is much rainfall and warm summer from June to October, and cool winter from February to May in the following year. Typhoon is an important resource of rainwater during Summer. Rice can be grown only during summer with some short dry spells. During cool winter, there is no paddy rice production.

All deltas show compatible utilization of climate, from the stand points of paddy rice production, however water use problem and sea water control are fundamentally important for the improvement of effective rainwater catchment system in the deltas of Asia.

2 Rivers and water utilization of Deltas

Concerning water utilization problems in deltas, not only rainwater but also the water in the rivers are important water resources.

(1) Rivers and water utilization in torrid Delta

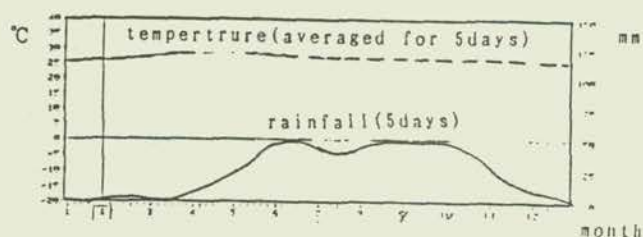
There are similar characteristics of water use in all deltas in Asia. The rivers and canals on the lower Deltas are as shown in the river model in Fig.2. There is one main river in the centre of the delta, and several tributaries, small rivers and many creeks. These are all important for ship transportations. They have the function of storing water resources in the rainy season, and for irrigation in the dry season.

As can be observed, there are similar distribution of the main river in the central part of the deltas, several tributaries, many small rivers and creeks in the Mekong, Chao Praya and the delta in Indonesia.

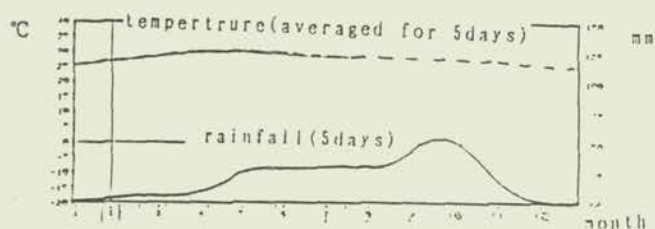
With regards to water utilization in the dry season, the fresh water from the main river has partially been introduced into the delta. There is serious shortage of fresh water during this season due to insufficient rain. The two kinds of water resources, which are rainwater stored in the creeks in the rainy season, and fresh water

introduced from the main river, should be utilized. There is serious sea water intrusion into all of the deltas observed.

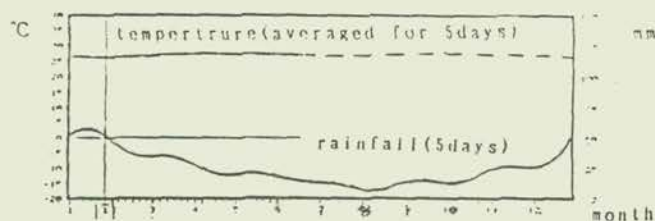
Mekong Delta



Chao Praya Delta



JAKARTA



Chikugo Delta

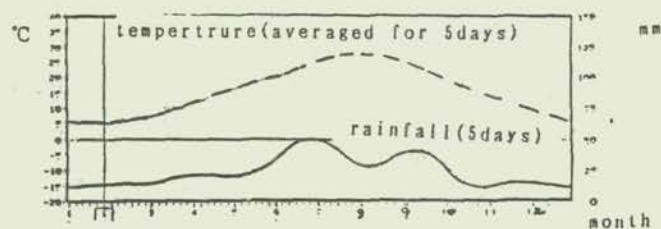


Fig.1 Seasonal distribution of 5-day rainfall and 5-day averaged temperature at Vietnam, Thailand, Indonesia and Japan

In the rainy season there is much rainwater. Some areas are flooded due to much rainfall and consequently, resulting in the depression of ground surface.

(2) Chikugo Delta in Japan

Chikugo Delta originally has the same characteristics as a torrid delta in terms of topography and water utilization, but now it is under construction of redevelopment project. There is a main big river called Chikugo, flowing through the central part of the delta to the Ariake Bay. There are tributaries from the main river, many small rivers and complicated canals and creeks. The Bay has tidal range of up to 5 meters during high tide. The estuary is stretched 30 km upstream from the river mouth.

For water utilization, at the present, the government has constructed one big tide barrage at the river mouth of the main river Chikugo, and several dams and weirs at the upstream and branches of the Chikugo river as shown in Fig.3. The important techniques of water use of Chikugo delta are described as follows.

- a) Big creeks were constructed to store rain water in the delta.
- b) Complex traditional customs of water use are reserved.
- c) "Spring water custom" where water is stored in each creek in series from downstream to upstream, before early summer every year.
- d) A special technique called "AO intake" which is a local technique of fresh water intake into the estuary. 200 special tide gates were constructed to help this traditional fresh water intake technique in the estuary.
- e) Though drainage condition has been very bad, stagnated water in depressions and creeks could now be drained through many small tide gates to the sea.

(3) water use problem

Though the three groups of deltas are located in different region on the globe; South East Asia, along the equator in Asia and East Asia, the distribution pattern of the main rivers, tributaries, small rivers and creeks in the delta have very similar characteristics. There is water shortage in the dry season or short spell of dryness in the rainy season.

As paddy rice production is the main business, water utilization is the most important factor in all the deltas.

Salt water control is the most difficult problem in order to solve water shortages. If we can effectively control salt water, splendid rainfed paddy rice fields can be produced without reservoirs construction at the main rivers and their watersheds.

3 Importance of compatible salinity control facility for deltas

With respect to actual salt water control, one example at hand is the Chikugo Delta, though it has too expensive works to be adopted in our model deltas. We conduct-

ed field survey to find out about the actual situation of deltas in 1994.

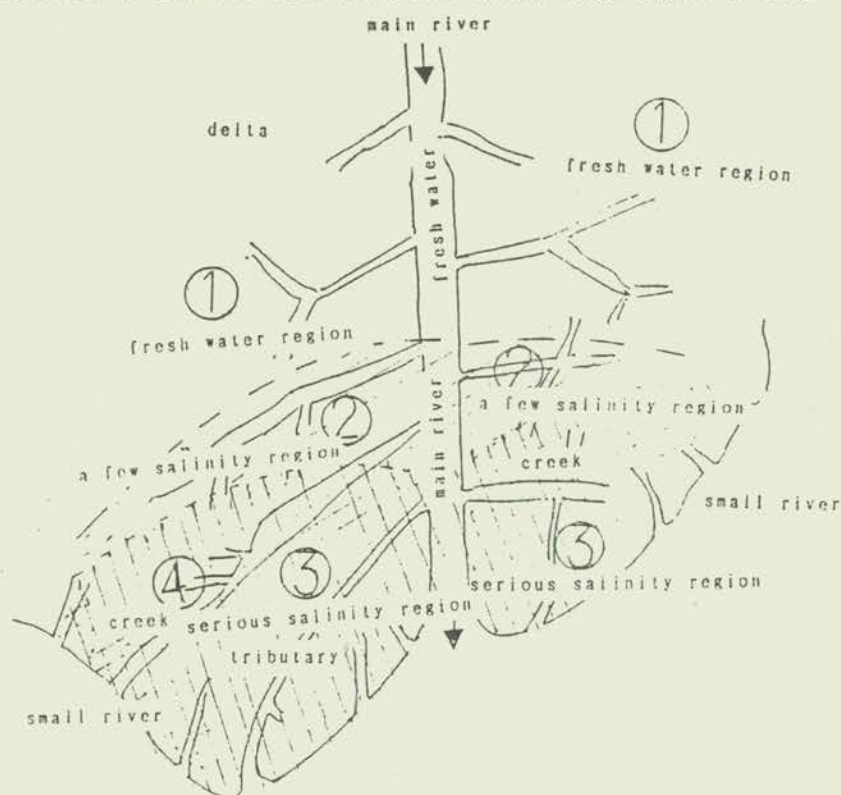


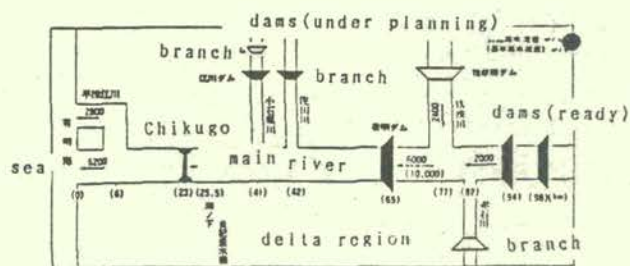
Fig. 2. Typical distribution of rivers, canals and creeks of the Delta (Mekong, Chao Praya, Indonesia and Chikugo)

(1) Mekong and Chao Praya Deltas

There is serious sea water intrusion through the water ways into these Deltas during dry season. They both have long sea coasts, and also many small rivers connected with the canals in the deltas.

The important findings from the survey of Mekong Delta are as follows.

- a) The present situation of salt water control at the feed canal which was constructed along the sea coast was generally not enough. Photo.1 shows the feed canal to prevent sea water along the sea coast. Photo.2 shows a tide gate at the cross point between feed canal and the river mouth. The people on this area wants more tide gate. Photo.3 shows the laborious operation by people at the inclined-type ship transport facility to cross the top of the embankment of feed canal. Photo.4 shows the closure bank which was constructed at the river mouth in order to stop salt water intrusion. Though this embankment can perfectly stop the salt water intrusion, but due to no navigation lock, the inclined ship transportation facility to cross the top of the bank was introduced.



(1) Distribution of water resources facility



(2) Water use systems
in the delta

Fig. 3 Re-development works of Chikugo Delta



Photo.1 Sea water feed canal

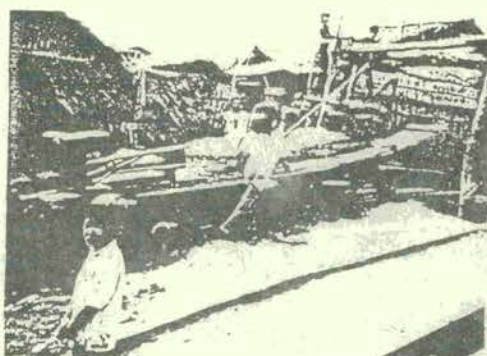


Photo.3 Inclined ship transport facility

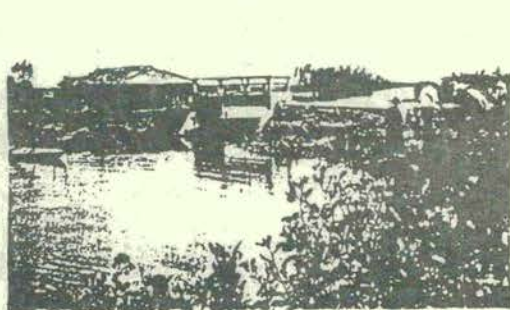


Photo.2 Tidal gate at feed canal

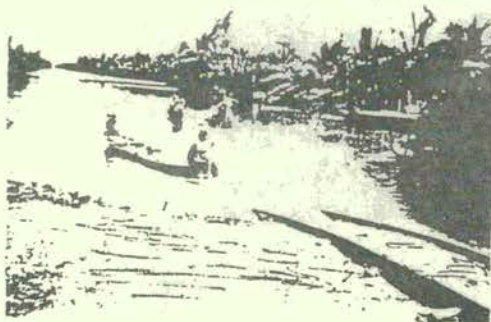


Photo.4 close bank of river mouth

(2) Salinity survey at Chikugo Delta

Chikugo Delta has also large amounts of sea water intrusion in the main river and all small rivers in the delta. To solve this situation and water intake problems from the main river during summer, the government has constructed a big tide barrage at 20 km upstream from the river mouth and several dams at some branches, as shown in Fig.3. They had developed "AO intake (surface water intake)" through the improvement of small tide gates. They also constructed complicated long canals and pipe systems in the Chikugo Delta as shown in Fig.3. For other small rivers they constructed many small tide gates to control sea water intrusion. The big canals and creeks are able to store the rainwater.

(They did not adopt the polder method or Wajyu method(Japanese) to prevent sea water intrusion.)

(3) Functions of FATG and M-NL to salinity control

To improve the construction cost problem to level up with the automatic control function of gate against salt water intrusion, Prof. Isao Minami have developed the floating automatic tide gate (FATG) and mini-navigation lock (MNL). The FATG works not only to stop the sea water intrusion in the dry season but also helps to drain off flood water to the sea in the rainy season. All boats can go through the M-NL to the upstream or downstream.

Then, we can put the fresh water of main river into the canals of the delta.

(1) Experiment model of FATG

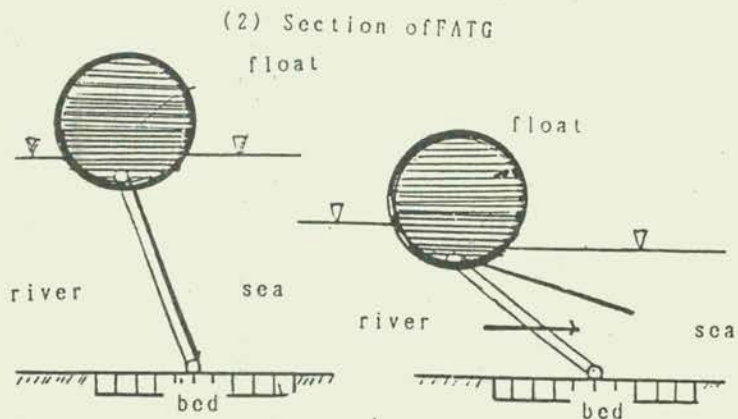
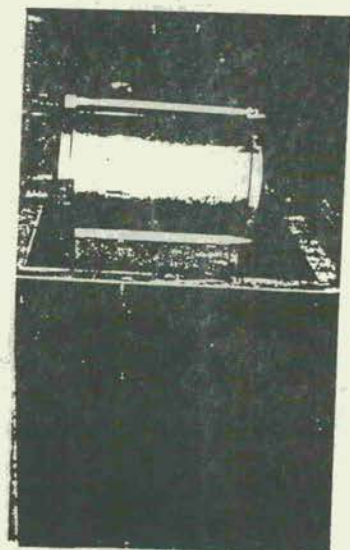


Fig.4 Floating Automatic Tidal Gate(FATG)

4 Toward effective rainfed paddy rice fields on Deltas

We would like to propose the following measures to develop the effective rainfed paddy rice field at Deltas in Asia.

- (1) Introduction of FATG and M-NL at the mouth of small rivers along the sea coast to stop sea water intrusion to the delta as shown by black boxes in Fig.5.
- (2) Introduction of FATG and M-NL in the salt water reach, along both banks of the main river as shown by black boxes in Fig.5.
- (3) Introduction of FATG and M-NL to the fresh water region in the upstream of the main river in order to allow fresh water from the main river to flow into the delta area as shown by the triangular boxes of void in Fig.5.
- (4) All rainwater can be stored on the paddy rice field.
- (5) Surplus rainwater from the paddy rice fields will be drained into canals, and stored in the canals and creeks.

Symbols:

R: total rainfall on paddy rice field in a life cycle of rice

ET: total evapo-transpiration from paddy rice field

Ap: area of paddy rice field

Q: fresh water discharge from main river

Ac=area of canals and creeks

Dc=depth of canals and creeks

Ti=irrigation period

(6) Water balance equations on the delta area

a) perfect rainfed agriculture

(a-1)

$$R = ET \quad (1)$$

(a-2)

$$R < ET$$

or

$$R \cdot A = (A_p \cdot ET + A_c \cdot D_c) \quad (2)$$

$$Q_c = A_c \cdot D_c$$

When there is deficit of water for paddy rice field in the dry season, we can again lift the water stored in the canals and creeks into the paddy rice field.

b) partial rainfed agriculture

A reasonable area and depth of canals can be studied by the water balance analysis using rainfall data, area of canals and creeks and the irrigation discharge Q from the main river.

$$A_p \cdot ET = A_c \cdot D_c + Q \cdot T_i + R \cdot A_p$$

(3)

The image of the control of sea water and the development of rainfed paddy rice field on delta can be shown as in Fig. 5.

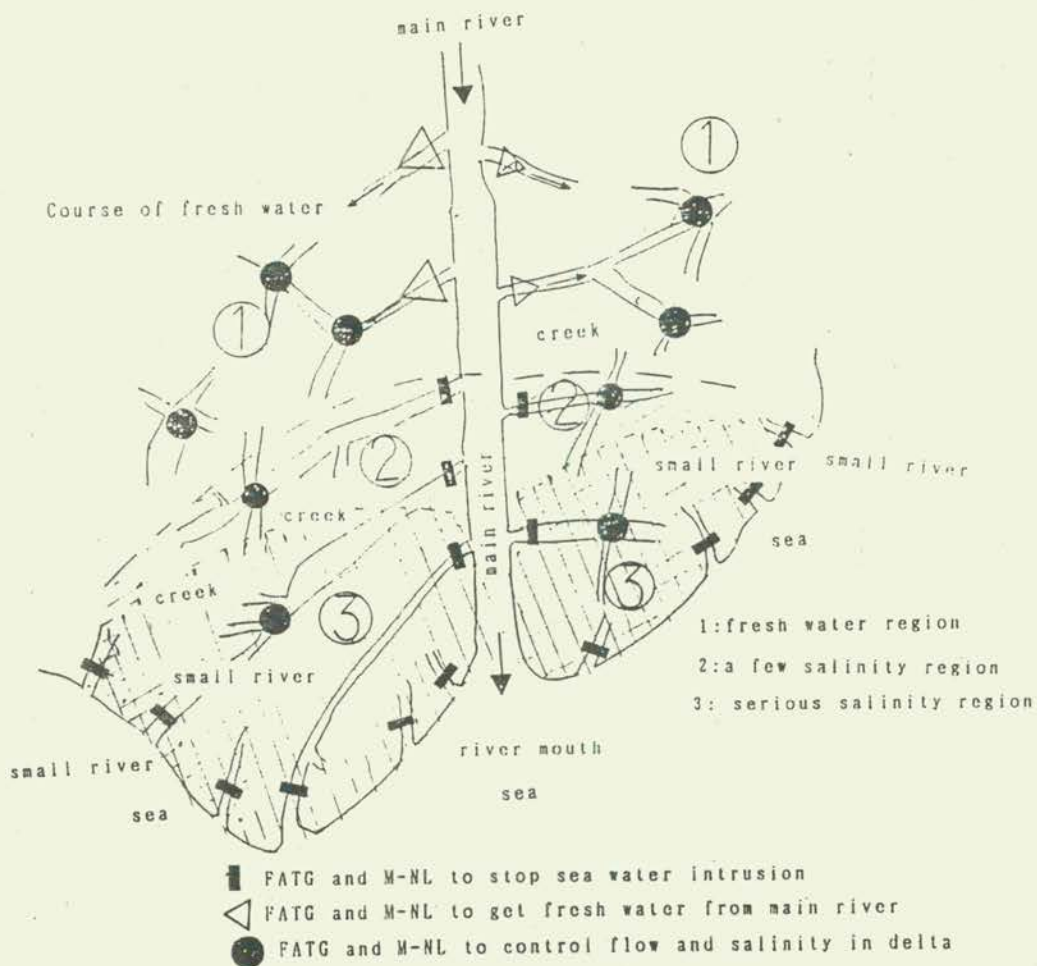


Fig. 5 Image of new development of rainfed agriculture of Delta by FATGs and MLGs

(7) Drainage improvement of rainfed agriculture

The drainage of the wide delta to the sea will be improved by FATGs.

(8) Economic problem of development

A more reasonable measures can be obtained introducing the FATG and M-NL instead of big barrage in the main river and long polder surrounding delta.

5 Conclusion

By comparison of water situation between three groups of deltas in Asia, we have come to the conclusion that, if refined rainwater catchment is introduced in the Deltas, more efficient paddy rice fields in Asia can be developed. To realize this goal the following can be exploited:

- a) Instead of the polder method, FATGs and MNLs should be constructed at the mouths of small rivers in order to stop sea water intrusion during the dry season, as shown in Fig. 5.
- b) Constructing FATGs along the banks in the upstream of the main river can be used to obtain freshwater from the main river into canals, in salt hazard deltas as shown in Fig. 5.
- c) Fresh water drawn from the upstream of the main river can flow into the saline water area through the skillful operation of the FATG and M-NL in the delta as shown in Fig. 5.
- d) FATGs will help in the drainage of flood due to accumulation of rainwater in the delta to the sea.

6 Bibliograph

- 1 Water resources used for cultivated plants in Vietnam :Bach Tyuet T.Vuong(Vietnam)
p.65 JIRCSA Vol.1No.1 July 1993
- 2 Design capacity of rainwater storages in the Seto Inland Sea Region : Hiroshi Okumura,
Isao Minami and Hiroshi Itagaki(Japan), p.13 JIRCSA Vol.1No.1 July 1993
- 3 Rainwater Use on Paddy Fields in Low-Lying Area: Akira Kudo, Jour. JIRCSA, Vol. 1, No. 1,
July, 1993, p. 5 JIRCSA Vol. 1No. 1 July 1993
- 4 Fresh water resources production by new Floating Automatic Tide Gate (FATG) in
estuary, Isao Minami, Noboru and Dojin Kobayashi,
p685-694, Proc. Regional International Conference, Kyoto, Oct. 1992

CURRENT STATE OF RAINWATER UTILIZATION IN TERRACING

AGRICULTURE AND ITS DEVELOPMENT IN GANSU, CHINA

Zheng Baosu*

1. Raise of the Issue

Situated in the interior, Gansu Province has long been known for its aridness in history. Drought and soil loss are the two most essential factors limiting agricultural development of the province as well as the chief cause for low yield and low efficiency of agricultural production.

1.1 Drought

In terms of drainage area, Gansu falls into the category of the three principal drainage basins of Huanghe, Changjiang and inland rivers. In terms of agricultural regionalization, it consists of dry farming area in east Gansu, central Gansu and south Gansu and irrigation agricultural area in Hexi Corridor. Dry-land farming depends mainly on scarce natural precipitation which ranges between 200 to 500mm and aridity, 0.9-2.9. Precipitation is not only deficient but is unevenly distributed with annual amplitude ranging between 1.8-2.9. Rainy season does not fit in crop water needed period. Water for agricultural purposes can not be guaranteed, which leads to low yield and low efficiency.

1.2 Serious soil and water loss

Because of sparseness in vegetation and inadequate ground coverage, gravitational and hydraulic erosion was induced as a result of rain drop splash and runoff scouring. Consequently, gully banks collapsed and gully heads advanced, and farmland diminished gradually. As soil nutrient was carried away by runoff, structure of tillage layer became coarsened, fat soil layer turned impoverished, soil organic content was only 0.5-1%, both nitrogen and phosphorus was inadequate and out of proportion, total nitrogen was 0.04-0.09%, and readily available phosphorus was less than 10ppm. As annual nutrient loss is higher than the amount of fertilizer applied, soil fertility declined constantly and productivity is not high.

1.3 Overpopulation

Average population density in dry-land farming area was 110 persons per sq. kilometer, the maximum can reach 400 persons per sq. kilometer. Because of overpopulated, many steep slopeland unsuitable to farming have to be turned into slope field at the expense of destruction of forest and grass. The extensive

* Gansu Provincial Bureau of Hydraulic Engineering
Lanzhou CHINA

cultivation, backward farming techniques and long crop variety replacement cycle have not only damaged agricultural resources, resulted in ecological disturbance but also led to the vicious cycle of "the poorer it is, the more land reclaimed, and the even poorer it would be".

Since the 1940s, work on experiment, demonstration and expansion of terrace project aimed at intercepting and storing rainwater and improving production have been carried out by a big margin in Gansu Province. The specific steps involved are 1) To turn slopingland with a gradient smaller than 25 degrees into terraces. Thus, over-percolated runoff was reduced, rainwater was effectively stored on terraced field, precipitation seepage was increased and soil moisture was increased. 2) To turn slopingland with gradient greater than 25 degrees into forest or grassland in a planned way. By so doing, the eco-environmental quality was improved and ecological balance was facilitated. Presently, terrace project has become the most important measure in agricultural production in dry-land farming area, and a magic weapon in agriculture of the province. Hence, it is particularly necessary to attach importance to the rational development of rain water utilization in a scientific way.

2. General Situation on Terracing in Gansu

2.1 In the two thousand years prior to the founding of New China, terracing had grown out of nothing

As early as 1942, soil and water conservation experimental plot was set up by Central Ministry of Forestry and Agriculture in Tianshui of Gansu to start field experimental project on soil and water conservation. Since the founding of the People's Republic of China, terracing has been hesitated to press forward and developed in a tortuous process. In the 1960s, terrace construction was mobilized and popularized throughout the province. Up to the mid 1980s, a steady development stage on terrace construction was witnessed, and a number of vital achievements in studies of terracing techniques, instruments for measurement and regionalization were obtained which effectively promoted technical development. As a result, an average increase of 50,000 hm was achieved annually. Up to the end of 1994, levelling terraces in dry-land farming area reached 1,152,700hm. The newly built 580,000 hm in the 14 years since the 1980s was equivalent to the total area built prior to 1980.

2.2 Various types of terraces in Gansu.

In terms of profile forms, levelling terraces and slope terraces are identified; in terms of layout, continuous terraces and terraces separated by slopes exist; in terms of ridge material composition, earthen-ridge terraces, rock-ridge terraces, and earthen-rock-ridge terraces are included; and in terms of soil moisture feed forms, rain-fed terraces, sand-compact terraces (sandy field) and irrigated terraces are distinguished. No matter what forms of terraces, they are all relevant to water resources,

rainwater utilization, soil fertilization and moisture preservation which are fundamental to terrace development.

2.3 Characteristics of terrace construction in Gansu

2.3.1 Formation of packaged technical system The target in terrace construction in Gansu is the realization of high quality, high efficiency, and high yield in construction, management and operation. Presently, standardization in management, packageablization in engineering, optimization in field plot design and scientificalization in construction have been basically accomplished.

2.3.2 Full-service in construction and production

An integrated full-service from terrace design and construction to means of production increase have been practiced. About 261,500 copies of popular science readings on terrace construction were published, 13,300 person/time attended 172 training causes and more than 450 pieces of optimized instruments were popularized in the province. A number of terrace demonstration plots, 745 demonstration townships, and 2805 demonstration villages were set up, demonstrated area covered 9433hm². There are 68 terrace-popularized townships and 977 terrac-popularized villages. In addition, relevant measures such as deep ploughing of virgin soil on newly built terraces, mellow soil reduction, manure addition, fertilizer application, and good strains of seeds utilization guaranteed no drop in production or even slight increase in production on newly built terraces.

2.3.3 Institutionalized administration

Large-scale terrace construction carried out in Gansu followed the principle of involvement of the State, local government and local people simultaneously. Input to per unit area was limited and subsidies given by the State was only 400 yuan per ha, and the major input was farmers' labour resources. Contract system covering administrative and technical aspects was introduced and contracts on terrace construction were signed by local government at various levels. Technical service networks were perfected, institutional aspects were strengthened, and technical service functions were emphasized which have promoted scientific, standardized and institutionalized development of terraces.

3. Scientific Basis for Terrace Construction

The following scientific principles are adhered to in terrace construction in Gansu.

3.1 Principle of soil and water conservation

Studies indicated that the greatest powers of runoff on slopes of a certain extent are runoff coefficient, precipitation intensity, slope length, and product of sine and cosine functions of slope angles. If any one of the above factors is zero, then the power

of runoff would be zero. According to this theory, the critical factors in reducing soil and water loss lie in change of angle of slope, shortening of slope length and decrease of runoff coefficient. In view of the above theory, the design of the terrace project can facilitate interception and storage of storm water through terracing.

3.2 Principle of system integrity and coordination

The function of complexed agroforestry ecosystem consisting aspects of field, road, forest, canal and pond as a result of slope farmland transformation is to give play to the role of water control, anti-erosion, disaster mitigation, and production increase. Road accessibility favors the improvement of field work and management efficiency. Utilization of trees, shrubs and grasses in the fields, peripheries and ridges lead to the formation of a vertically mosaiced and intermingled landscape which enables the full utilization of light, heat, water, and nutrient. Canals and ditches form a feedback regulated circuit of water which further improves field moisture environment and meets the target of production increase.

3.3 Principle of multi-purpose optimized decision-making and satisfactory solution

In the process of designing optimized plots, contradictions exist among the four targets, i.e., contradiction between narrowing plot with less labour required and widening plot for mechanical operation, and that between less land occupied required steep ridges and terrace safety and stability. To this end, it is necessary to turn multi-purpose function into single target function; to gain secondary optimized satisfactory solution if the optimized solution could not be given; to give prominence to the role of sensible factors and take non-sensible factors as peremetric variations or constant; and to make mathematic models being adaptable to different terrace types, and different stand conditions without complicating the models. Practice proves that optimized design scheme given by DSS/T operation is far superior to imperial scheme.

3.4 Principle of scale efficiency

In terrace project, construction cost is directly proportional to farmland area. However, since degree of project concentration and scatteredness differs, administration fee to planning, design and test is not directly related to farmland area but normally in logarithmic relation. In certain scope, the large the project, the total cost allocated to unit area would be less. This is referred to as scale efficiency. Taking into account of the laborers going there and back, domestic supply, crops for rotation and existing productivity, plot under proper scale management would be 5-10hm, communes and villages are proper units based upon.

3.5 Principle of ecology

According to theory of ecology, organism is divided into narrow-spectrum species and broad-spectrum species adaptable to environmental changes. In the light of this principle, terrace project design, in addition to not to disturb top-soil layer, reduce fertility loss of living soil layer, receive soil moisture, increase porosity, add organic fertilizer or manure, nitrogen and phosphorus fertilizer and select crops tolerant to original soil in the newly built terraces, the principle of "safety first and production increase next" should be adhered to in determining relationship between collection area of terraces and slope flow yield. In recent years, the amount of precipitation in dry-land farming area is based on to calculate collection ratio in designing flood and sand utilization, which was taken as design basis of continuous terrace and slope-separated terraces. Meanwhile, experience on terrace construction in summer was also popularized in east Gansu, and storage of autumn rainfall was done so as to realize the goal of turning autumn rainfall for spring purposes. The results are fairly promising.

4. Efficiency of Terrace Project in Gansu

With constant expansion of area, the role of terraces in developing agricultural production, improving eco-environment, and eliminating poverty for local people has become more and more obvious.

4.1 Efficiency of "three preservations" of terraces

The principal limiting factors to dry-land farming in Gansu are water and fertilizer, and terracing has increased the ability in water storage, mud interception and fertility keeping. Studies on soil and water conservation carried out by soil and water conservation department showed that terrace project can intercept and store all the available rainwater. The amount of water intercepted on per ha of terraces per year is 600-750 cubic meters more than the sloping land, and mud intercepted is 45-75 tons. Calculations based on the above facts indicated that there are 1,152,700 hm² of terraces in the province, annual average water stored was 778 million cubic meters, mud intercepted, 69.16 million tons, and can preserve 250,000 tons of nitrogen, phosphorus and potassium nutrients. Measurements indicated that soil moisture content in old terraces built more than ten years ago increased by 6-11.6%, water soluble nitrogen by 1.4 times, readily available phosphorus increased by 14%, and readily available potassium by 1.163 times.

4.2 Efficiency of production increase by terraces

In the light of the expansion projects on optimization of terraces carried out by Bureau of Soil and Water Conservation of Gansu during 1991 to 1993, yield estimation on 1,873hm² of slopingland, 2,440hm² of ordinary terraces, and 1,707hm² of optimized terraces was conducted in eight prefectures (zhou or cities). Estimated results on an average level are as follows:

slopingland, 19,965kg/hm ; ordinary terraces, 2592kg/hm ; and optimized terraces, 3010.5kg/hm ; ordinary terraces increased by 30% in contrast to slopingland and optimized terraces, 50.8% than the slopingland. Calculations based on the above figures showed that an increase of grain production merely from terraces was 714 million kg annually. The highest per capita terraces available is in Dingxi of Gansu, from 1949 to 1982, the number of year with total yield exceeding 100 million kg was only five years. Upon entering the mid 1980s, the area of terraces has been constantly expanded. Since 1983, grain yield in ten years running has exceeded 100 million kg, and in 1991, it was 127 million kg.

4.3 Great potential in yield increase on terraces

Follow-up investigations on grain production carried out in 1990 in Pingliang Prefecture on 860hm of newly built terraces showed that the average yield of wheat was 3277.5kg/hm , the highest, 6570kg/hm . Yield of maize on mulched experimental plot on old terraces in Chaipeng Village, Leida Township of Ningjing County in the prefecture was as high as 1419 kg/hm . Meanwhile, orchard was developed on terraced fields, economic crops like Chinese prickly ash and day lily were planted on ridges, vertical agriculture got developed to a considerable degree which benefitted a great deal.

5. Prospect on Terraced Field Development and Utilization of Rainwater

5.1 Prospect of terraced field development

In 1991, provincial government of Gansu decided to put the 1.333 million hm of "three land" (land of water, soil and fertilizer conservation) under the strategic programme of "22274" project accomplished by the end of the century. The 1990s can be referred to as a brand new stage for terraced field development.

5.1.1 Agricultural regionalization data of gansu reveal that there are 3 million hm of slopingland of 5-25 degrees in the two major drainage basins of Huanghe and Changjiang. This provided rich land resources for terrace construction in the province. According to the provincial ten-year programme and 8th-Five-Year Plan, 50,000 hm of "three land" will be dealt with yearly in the future. With the deduction of land for industry and mining activities as well as for domestic usage, the actual land of the kind will be 1,467,000 hm and total grain production may exceed 3 billion kg by the end of the century. In recent years, about 60,000 hm of "three land" have been improved annually, of which terraced field occupied over 93%. Prospect of terrace project in Gansu is quite promising. It is anticipated that terracing will be realized in five counties and 155 townships at turn of the century, and the area of "three land" may cover 2,467,000 hm by the year 2020, terracing can be realized in most of the counties in dry-land farming area.

5.1.2 By summing up the past thirty years experience, future

terrace construction should follow the guiding principle of "overall planning, attach importance to quality, strengthening management, emphasizing efficiency, and advancing energetically". Analysis of recent ten year's work indicated that future terrace construction at an annual average rate of 0.007hm per capita or 0.02 hm per labour would be suitable.

5.2 Prospect of rainwater utilization

After several decades' development, a perfect institutional system covering administrative, technical and personnel aspects have been formed, and a batch of engineering technical personnel and farmer technical personnel have been trained which provided sufficient technical guarantee for large-scale terrace construction, and accelerating exploitation of water and land resources. The future development orientation in terracing is to improve quality, pay attention to efficiency, add rainwater utilization measures and promote high quality, high yield and high efficiency of terracing.

5.2.1 Perfect slope engineering system, and improve disaster prevention capability of terrace project. The principle of "a project of vital and lasting importance and quality first" should be followed, technical service should be strengthened, input increased, production increase measures comprehended, and per unit area production raised.

5.2.2 Packaged project system on rainwater utilization should be gradually formed. Taking terrace project as the pillar, water pit, waterlogged pond and warp land as well as key project of control ditches should be developed substantially. Over-percolated runoff induced flood should be controlled by taking small catchment as unit. Irrigation of terraces should be realized by means of lifting irrigation and artisan irrigation. To realize the goal of compensating water deficit years with water stored by means of intercepting and storing water locally for local use.

Research of Flood Rainwater Utilization in Beijing Municipality^①

Hui Shibo^② Xie Senchuan^③
(Tsinghua University, Beijing, 100084)

ABSTRACT

Beijing is a serious water shortage city in China. Owing to overpumping groundwater in the last 10 years, the situation of rainfall infiltration—runoff relation of hydrologic cycle has greatly changed in both urban and rural area. In the article the characters of rainfall and flood runoff and their changes have been discussed. For studying the usability of flood rainwater to recharge groundwater the water quality condition of runoff from roof, road and greenland has been presented. The implementation of the roof collection and infiltration recharge well system in urban area and its effect has been introduced. The study of the field rainfall infiltration regular pattern and the experimental work of rainfall—flood utilization in rural area has been analysed in detail.

INTRODUCTION

The amount of water resources in China takes the sixth place in the world, but the average value per capita has only one fourth of the world average. Beijing as the capital of PRC with 11 million population only takes 15% of the average water resources value per capita in whole country. In the last more than 10 years, the contradiction of water supply—demand has become increasingly sharp, especially, in the eighties, even the water crisis occurred.

Beijing lies on the north end of Huabei plain and has the area of 16800km². Among them the plain region takes one third. Owing to the characters of natural geograph and monsoon climate, the distribution of precipitation in years and in months of a year is very uneven. In most rainy year 1956 the regional average precipitation reaches to 1385.5mm, and in the most drought year, it has only 311.2mm. The difference between them takes more than fourfolds. In a year, almost 80%~85% precipitation always concentrates in the rainy season. According to the statistical data the amount of multiyear average runoff in flood season reached $0.95 \times 10^9 \text{m}^3$. Even in two typical drought years 1980 and 1981, there were still $0.12 \times 10^9 \text{m}^3$ runoff, flowed out from the region. Hence, the utilization of runoff in flood season has significant meaning for mitigation of water shortage of Beijing.

On the plain area of Beijing, especially on the top area of alluvial fan of Yongding River, there is a quite thick and wide spread sandy—gravelly permeable layers with fine infiltration and storage condition. If some storage—recharge construction would be carried out, the more will be groundwater recharged. In the wide range plain area, owing to the overpump and successive drought, the groundwater table has become a widespread drop. Thus, it is preferable to increase rainfall infiltration for regulation and storage of rainfall in flood season. Therefore, to develop flood rainwater utilization and to retain rainfall in flood season for recharge are the effective measures for mitigating the water crisis in Beijing.

① This research project was jointly completed by Beijing Municipal Water Conservancy Research Institute, Hydraulic Engineering Department of Tsinghua University, Beijing Municipal General Hydrometric Station etc. In the presented paper the research results of above listed other institutions have been quoted. The authors gratefully acknowledge the generous help for the paper provided by the above mentioned organizations.

② Professor of Hydraulic Engineering Department of Tsinghua University, 100084, Beijing

③ Associate Professor of Hydraulic Engineering Department of Tsinghua University, 100084, Beijing

The research project of rainfall—flood utilization in Beijing has been supported by the National Natural Science Foundation and Beijing Municipal Water Conservancy Bureau. The research program included: the analysis of characters of rainfall and runoff in flood season for studying the standard of rainfall—flood utilization; the analysis of water quality condition of natural rainfall and runoff from greenland and road for studying usability; the implementation of the roof infiltration well recharge system and lawn rainfall storage system in urban area for studying the strategy of flood rainwater utilization; the implementation of rainfall—flood utilization experimental area with 10 to 200 km² in rural area for studying the rainfall infiltration recharge regularity and the strategy of rainfall—flood utilization in rural area.

THE ANALYSIS OF RAINFALL AND STORM IN FLOOD SEASON

Rainfall and Storm According to 40 year series data (see table 1) of ten hydrological stations, the analysis of rainfall in plain area is as follows:

Table 1 The Statistical Data of Rainfall in Plain Area of Beijing

NO	P%	1	2	5	10	20	50
1	yearly precipitation (mm)	1369.6	1254.4	1094.4	966.4	825.6	601.6
2	precipitation in flood season (6—9) (mm)	1208.4	1102.4	948.7	826.8	699.6	492.9
3	②/①×100%	88.2	87.9	86.7	85.7	84.7	81.9

From the table above it could be seen that the concentration degree of rainfall in flood season become more as the frequency is decreased. The main character of rainfall in flood season is the storm will high concentration, large intensity and high frequency. According to the analysis of 94 year data in the Haihe River basin, the characters of storms are shown as in table 2.

Table 2 The Statistical Data of Maximun 1 Day, 3 Day, 7 Day Storm in Plain Area of Beijing

Items Frequency p%	Rainfall (mm)			Max. 7day Rainfall in flood season (%)	Max. 1 day Max. 7 day (%)
	Max. 1 day	Max. 3 day	Max. 7 day		
1	403	455	556		
2	346	387	489		
5	259	308	399	41.4	65.0
10	201	250	331	39.5	60.7
20	144	190	258	36.5	55.8
50	86	110	154	31.0	55.8

Storm Runoff Though the groundwater table in urban area is a funnel shape due to over pump, the storm runoff became a sharp bell with high peak value owing to the urbanization, which decreased the impermeable area of watershed. For instance, on Aug. 10th 1984 the areal average precipitation in the Tonhua River basin was 98.1mm with corresponding flood peak discharge 323m³/s, but on July 21st, 1958, the areal average precipitation was 120mm, its corresponding peak discharge took only 164m³/s (see table 3).

From table 3, it can be seen, that the urbanization caused the increment of flood—runoff amount and flood peak discharge, as well as threatened the flood protection of cities.

Table 3 The Comparison of Storm Runoff in Tonhua River Basin

Items	1959. 7. 21		1984. 8. 10		1984 1959
	areal average	P%	areal average	P %	
Max. 1 day precipitation (mm)	120.1	30	98.6	50	0.82
Max. discharge (m ³ /s)	166.0		323.0		1.95
The amount of runoff (10 ⁴ m ³)	455.4		479.0		1.05
Average runoff depth (mm)	50.6		53.2		1.05
Factor of runoff	0.42		0.54		1.29

On the contrary to urban area, in the rural area the groundwater table also has dropped down with 0.5~0.6m per year in the average, but the flood runoff appeared the obvious decreasing tendency. For instance, the Tiantang river basin of Daxiang county, located on the south of Beijing, is a flat and low agricultural region with area of 279km². The groundwater depth was dropped from 2 m in 1979 to more than 8m in year 1984. It caused great changes of flood—runoff (see table 4).

Table 4 The Comparison of Twice Stown—Runoff in Tingtang River Basin of Daxiang County

Items	1979, 8. 9—8. 15		1984, 8. 6—8. 12		1984 1979
	areal average (mm)	corresponding frequency (%)	areal average (mm)	corresponding frequency (%)	
max. 7 day precipitation	208.5	33	259.1	20	124.3
max. 3 day precipitation	121.5	45	234.9	12	193.3
max 1 day precipitation	92.9	45	141.4	20	152.2
antecedent 1 day precipitation	22.9	...	40.4	...	176.4
Max. discharge (m ³ /s)	148.0		7.35		
Total volume of runoff (10 ⁴ m ³)	360.2		83.6		
Average runoff depth (mm)	129.4		3.0		
Factor of runoff	0.62		0.01		

The table showed that the changes of ground surface condition by human activities caused the great decrease of flood runoff. If the storm has frequency more than $p=20\%$, there will be almost no runoff.

ASSESSMENT OF FLOOD WATER QUALITY AND ITS USABILITY

Water Quality Assessment Using the State Surface Water Environment Standard (GB3838—88) for evaluation, the Beijing Municipal General Hydrometric Station monitored and analysed the water quality of natural precipitation & runoff from roof road and greenland in the flood season both in urban and rural areas. The conclusions are as follows:

- The water quality of natural precipitation and runoff from roof and road belongs to V class standard, and runoff from greenland belongs to III class standard.
- The pollutant contents of runoff from road are decreasing with the duration of rain. Because of that the atmospheric compositions were relatively stable during the rain, so the contents

of ammonium nitrogen has not greatly changes during rainfall.

- The main sources of pollutant of urban runoff are accumulative pollutants on the ground surface. The water quality of runoff is worse at the beginning, soon afterwards the pollutant contents are decreasing fast. So some reasonable approaches should be taken such as, the first time storm in a year on the forepeak of runoff should not be used for storage and recharge.

- If there are not obvious pollutant sources, the flood—runoff from farmland entirely coincides with the water quality reference standard for recharge (Water Quality Controlled Standard for Groundwater Drainage, USA, and Water Quality Standard for Artificial Groundwater Recharge, Shanghai)

Usability Owing to the urbanization and to the increment of mist and cloud dust in air, the natural precipitation has been polluted. According to the State Surface Water Environment Quality Standard (GB3838—88), based on the analysis of composite index assessment method, the natural precipitation has been worse than V class standard. In the case of rainfall—flood utilization in urban area, the real situation must be considered. If too restrict standard for recharged water is required, it will be unrealistic. For promoting improvement of environment situation of groundwater in urban area, it is feasible to require the recharge water to satisfy III class standard, which is for 2nd grade water source protection region for concentrated drinking water.

The organic mater produced in runoff from greenland dissolved fastly, it reflects the role of lawn to water quality puryfication. So using greenland to retain floodwater for recharge groundwater should be sufficiently used. For the runoff from roof, exopt the organic pollutant, which is overstandard, other items all satisfy 1st, 2nd class standard. Therefore, if some suitable measures would be taken, it is not difficult to reach 3rd class standord for recharge use.

For the farmland region, in the condition of that there ore not obvious pollutant sources, such as community enterprises, garbage heap etc, compared with water quality reference standard inside or abroad for recharge, the flood runoff can be sufficiently utilized for recharge groundwater.

RESEARCH OF RAINFALL—FLOOD UTILIZATION IN URBAN AREA

The planned urban area of Beijing has 1024km², which lies on the slight inclined flunial plain between Yongding river and Wenyu river, its topograph is from north—west to south—east. In urban area there are some drainage rivers, such as Tonghui river, Lianshui river and Liangma river etc. (See Fig. 1) Within the planned area of 1024km², the constructed area has reached 394.5km² in year 1989. In the recent years, the construction scope developed rapidly and the urban area still expended continuously.

In the west suburb of Beijing there are a large area of sandy—gravelly aquifers buried shallow and thinck, it is a very favourable condition for retaining—storing and infiltration of rainfall flood. In the urban area the thickness of aquifers gradually decrease from north—west to south—East, and lithologic character changes from coarse sand to fine sand. But under the depth of 4—5m, generally there are layers of medium sand or fine sand. So in the urban area collection of runoff from roof—ground and through infiltration well system could be used for recharge, and the greenland is a realistic site for retaining and infiltrating. We could give full play to greenland for runoff water quality puryfication and recharge.

The Experiment of Roof—Infiltration Well System In the experimental plbt an infiltration well has been maintained for collection of roof runoff from an area of 374m², its engineering scheme, shown in Fig. 2, included small conveyance channel and an infiltration well with diameter of 3m, depth of 6m, and volume capacity of 42.6m³. The soil around the well is silt loam with stable infiltration rate $k=5\times 10^{-5}\sim 2.0\times 10^{-4}$ cm/s, and the soil under the bottom of well is fine sand and medium sand with quite good permeability $k=(1.0\sim 5.0)\times 10^{-3}$ cm/s

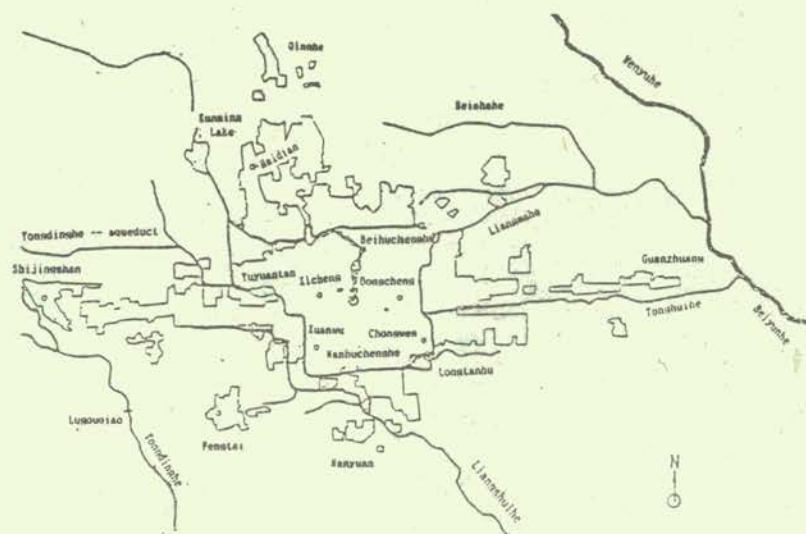


Fig. 1 The Urban and Suburb Area of Beijing and Its Drainage River System

In 1990~1991 The artificial recharge experiments have been carried out many times. The two—dimension column coordinate system soil water movement fundamental equation with variable parameters θ (soil water content) and h (water head) have been established respectively. The θ and h equations of infiltration are as follows:

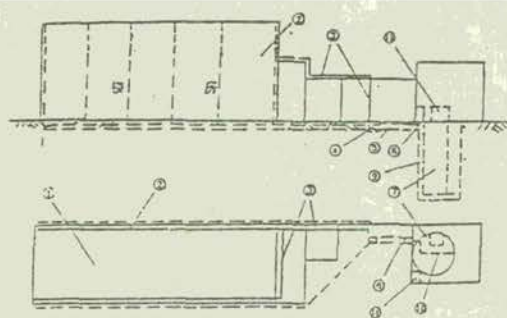
$$\theta \text{ equation } \frac{\partial \theta}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} (rD(\theta) \frac{\partial \theta}{\partial r}) + \frac{\partial}{\partial z} [D(\theta) \frac{\partial \theta}{\partial z}] - \frac{\partial K(\theta)}{\partial z} \quad (1)$$

$$h \text{ equation } C(h) \frac{\partial h}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} [rK(h) \frac{\partial h}{\partial r}] + \frac{\partial}{\partial z} [K(h) \frac{\partial h}{\partial z}] - \frac{\partial K(h)}{\partial z} \quad (2)$$

here, Z —vertical coordination, downwards is positive; r —radial coordination; θ —soil water content (cm^3/cm^3); $D(\theta)$, $K(\theta)$ —unsaturated soil water diffusivity (cm^2/s) and conductivity (cm/s) respectively; h —water head (cm); $C(h)$ —specific water capacity. These two equations could be solved by ADI finite differential method in r and z two directions. According to measured data of infiltration well, the changing process of the infiltration rate $i(\text{cm}/\text{min})$ on unit area of well infiltration surface could be got. The comparison of measured and calculated results of two mathematical models are all shown in Fig. 3. It showed that the calculated results of h equation is well fitted with measured data.

Table 5 The effect of infiltration—regulation of infiltration well ($d=3\text{m}$, $h=8\text{m}$)

NO	Frequency of rainfall (%)	Roof area (m^2)	Total inflow volume to well (m^3)	Total outflow volume from well (m^3)	out flow in flow $\times 100\%$
1	50	6000	490.4	0	0
2		7000	571.9	8.16	1.4
3		8000	653.6	25.96	4.0
4	20	3000	410.4	0	0
5		4000	547.2	4.13	0.8
6		5000	684.0	35.08	5.1
7		6000	820.8	76.12	9.3
8	10	2000	381.9	0	0
9		3000	572.9	8.32	1.5
10		4000	763.8	59.02	7.7



① roof collection site ② rain pipe ③ PVC water conveyance pipe
④ head pond ⑤ ditch ⑥ triangular weir ⑦ infiltration well
⑧ entrance to well ⑨ conveyance pipe ⑩ pipe with holes
⑪ rate meter ⑫ automatic water gauge

Fig. 2 The Infiltration Well System

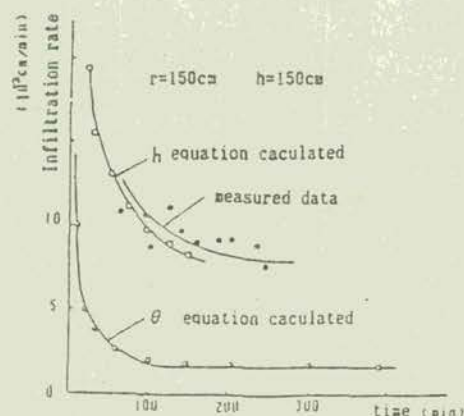


Fig. 3 The Comparison of Calculated Results With Measured Data

In 1990—1993 years the rainfall in the flood season on the experimental roof has been conducted entirely to the infiltration well for recharge. Because of that the experimental roof area was restricted by the objective conditions, so the infiltration well system could not be used sufficiently. For assessment of the potential realistic effect to the retain and acceptance of rainfall of the system, the infiltration—regulation effect of infiltration well with 3m diameter and 8m depth in the condition of one day rainfall with different frequency ($p=5\%$, 10% , 20% , 50%) in different collection area was shown in Table 5. For making full play to infiltration well, the design standard of well should not be too high. If the design standard of well takes the 1 day rainfall with frequency $p=20\%$, every well ($d=3m$, $h=8m$) can collect the roof area of $5000\sim 6000m^2$ for recharge.

Retain—Infiltration—Recharge Experiment of Greenland On the experimental area the lawn has been arranged with different pattern. One has the same level with round land, the other is lower than round land for partial acceptance of surface drainage water to lawn. In the lawn experimental plot a set of tensometers has been installed to measure water content of the profile for to calculate soil water movement flux on different depth, as well as to analyse the recharge value from rainfall. In 1990~1991 two year observed period there happened 59 times rainfall during the nonflood season, because of small intensity the rainfalls were fully infiltrated without any runoff. In 1990 from July to September the precipitation was 443 mm, in 1991 from May to August was 493.6mm. In the two years the effect downward infiltration fluxes on the 1m depth are shown in table 6. In urban area of Beijing the top soil generally is loam, which has stable infiltration rate of

Table 6 The Comparison of Inflow and Infiltration Amount on Different Type of Lawn

NO	Item	Type	medium level lawn	lower lawn *
1	Precipitation amount	(mm)	936.6	936.6
2	Irrigation amount	(mm)	115.0	113.6
3	Total	(mm)	1056.1	1050.2
4	Downward infiltration amount at 1m depth	(mm)	194.6	312.7
5	4/3	(%)	18.5	29.8

* The inflow to lawn has not been included in

$(1\sim 5) \times 10^{-4} cm/s$. The lawn will not be ponded under common rainfall condition in the flood season. Even if happened the storm of max. 24 hr precipitation of $201\sim 289mm$ with frequency $p=5\% - 1\%$, the lawn also will not be ponded more than two days to influence growth of lawn

and to destroy the landscape. Therefore, the attention of great potentiality of greenland for infiltration and recharge should be given for effective utilization of rainfall—flood.

The Typical Analysis of Effect of Rainfall flood Utilization The development of rainfall Flood utilization in urban reea could lighten the frequent flood disasters caused by urbanization and changes of hydrological condition, and could mitigate the overpump of groundwater. As an example, in Aug. 10th, 1988, it happened a storm in urban area with daily precipitation of 98.1mm, approaching to frequency $p=5\%$. At the station Lejie Garden with watershed 90km^2 , the measured max. discharge was $300\text{m}^3/\text{s}$, the flood volume was $479 \times 10^4 \text{m}^3$. If the rainfall flood from roof and ground of constructed area which has accounted to 40% of watershed area, could be conducted to infiltration well. And greenland accounted to 20% could be bordered for retaining rainfall. Based on the analysis, the flood runoff would be greatly changed. After the utilization of rainfall—flood the peak discharge will decrease by 46% and the infiltration recharge amount will reach $287 \times 10^4 \text{m}^3$, which accounted to 62% of flood volume.

RESEARCH OF RAINFALL FLOOD UTILIZATION IN PLAIN AREA

General Situation of Suburb Plain of Beijing Beijing has plain area of 6400km^2 , in which there are $5 \times 10^6 \text{mu}$ farmland. Irrigation water is mainly taken from ground water. In the eighties the groundwater table successively dropped down in $0.5 \sim 0.6\text{m}$ per year. In 1990, the buried depth has reached below $6 \sim 8\text{m}$, and even below 20m in some area. On one side the groundwater is seriously overpumped, on the other a plenty of runoff was still discharged. As in the drought period of eighties the average annural precipitation was 525mm ; which was less than multiyears aresage value by 12.5% . But in the ten years the flood discharge volume still had $2.4 \times 10^9 \text{m}^3$. In the plain area, more than 80% of top soil is sandy loam and silty loam, which has good infiltration character. So the precipitation in flood season should be sufficiently used to increase recharge for groundwater. After fourty years water conservancy construction an integreted irrigation drainage system has been formed. On the river system of plain area there are more than 210 sluices, which has the total capacity of $(80-100) \times 10^6 \text{m}^3$, among them 10 sluices each has the capacity more than $1.0 \times 10^6 \text{m}^3$. If a slight reconstruction for drainage system would be taken, the drainage system could play two functions: "storage for recharge, open sluice for discharge". To retain the plood in drainage system will get a fauourable condition for recharge groundwater.

The Research of Rainfall—Flood Utilization in Plain Area For getting the precipitation infiltration regularity of farmland in the condition of more than $5 \sim 6\text{m}$ water table depth, the research work adopted the method of mathematical model connected with necessary experimental test on the yield. In the study soil water movement parameters have been measured, and the spacial variability of field infiltration in the different scale has been analysed. The field infiltratrom could be expressed as a one—dimensional vertical unsaturated soil water movement, which could be shown as follows:

$$\frac{\partial}{\partial t} = \frac{\partial}{\partial z} \left[D(\theta) \frac{\partial \theta}{\partial z} \right] - \frac{\partial K(\theta)}{\partial z} \quad (3)$$

where the illustrations of symbols are as for formula (1), (2), Applying numerical calculation, the results of infiltration process of sandy loam with different initial water contents under two kinds of infiltration boundary conditions are shown in Fig. 4, 5.

The Analysis of Rainfall—Infiltration Process In the rainfall process the intensity is changing with time. If we directly use the formula(3) to solve the rainfall—infiltration process,

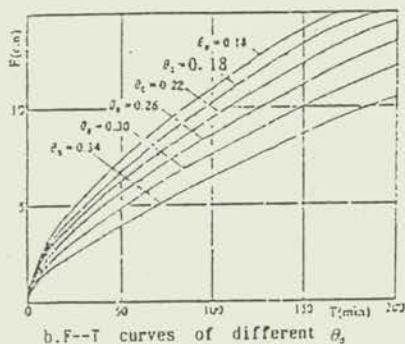
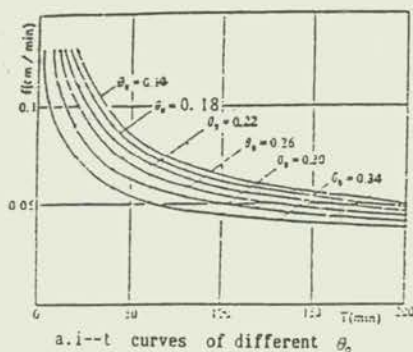


Fig. 4 Calculated Results of Ponding Infiltration (Sandy Loam)

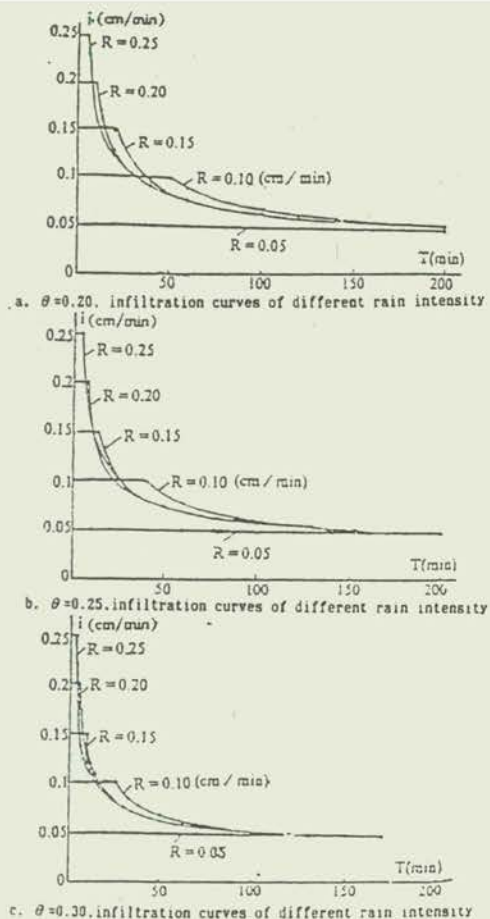


Fig. 5 Calculated Results of Uniform Rainfall (Sandy Loam)

the calculation will be very complicated. In this study, according to the formed conceptive rainfall-infiltration model the process of rainfall infiltration could be easily solved. Using the calculated results in Fig 4, 5, the relationship between infiltration rate f and corresponding to infiltration amount F for same kind of soil with same initial water content has been obtained. For sandy loam the relationship of $f-F$ was shown in Fig. 6. It could be seen that the relationship of $f-F$ for two kinds of infiltration boundary condition almost located on some curve. On double logarithm paper the relationship of $\log f - \log F$ appeared a set of straight lines in same slope. (see Fig. 7). According to numerical calculation of the infiltration process for four kinds of soil as sandy loam, silty loam, medium loam and heavy loam in the two kinds of boundary condition, we obtained the conceptive expression of infiltration rate f with variables θ_0 and F as shown in table 7.

Table 7 The Relationship of $f-F$ For Different Kind of Soil (f -cm/min, F -cm)

NO	Soil	Formula
1	Sandy loam	$f = (0.605 - 1.37\theta_0)F^{-0.726}$
2	Silty loam	$f = (0.513 - 1.05\theta_0)F^{-0.868}$
3	Medium loam	$f = (0.0511 - 0.115\theta_0)F^{-0.865}$
4	Heavy loam	$f = (0.00536 - 1.0126\theta_0)F^{-0.971}$

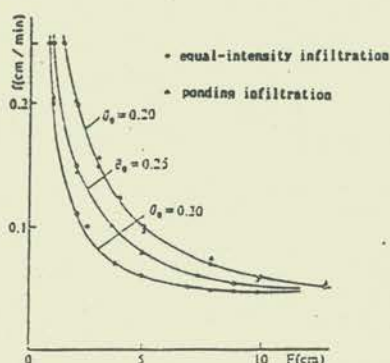


Fig. 6 Relationship of $f-F$

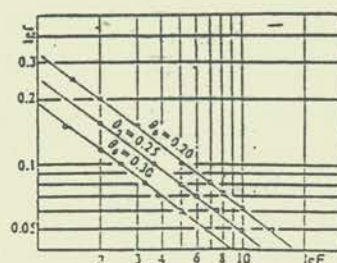


Fig. 7 Relationship of $\lg f - \lg F$

Table 8 The Calculation Results of Rainfall—Infiltration—Ponding Process for Different Soil

Soil	Daily precipitation (mm)	Duration of precipitation (min)	Initial time of ponding (min)	Ponding recession (min)	Max. ponding depth (mm)	Ponding depth / Precipitation (%)
Sandy loam	173	650	390	640	39.7	22.9
Silty loam	173	650	380	730	48.7	28.2
Medium loam	173	650	150	2609	127.7	73.6

The Analysis of Rainfall Infiltration in Field For Different Soil According to above listed $f-F$ relationship, the infiltration ponding process in any time of rainfall process for different soil could be analysed. For instance, in August 9th 1984 in Daxian county there was a daily rainfall of 173mm, corresponding to frequency $p=15\%$. Based on calculation, the infiltration ponding process was shown in Fig 8. The result of calculation in Fig 8 was in the condition of past precipitation and antecedent soil moisture $\theta_0=0.30$, which approached to field capacity. The calculation results of rainfall—infiltation—ponding for different soil were shown in table 8.

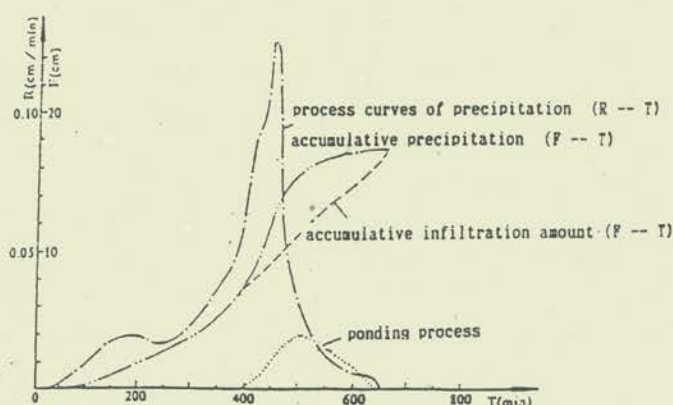


Fig. 8 Rainfall Infiltration—Ponding Process
(Sandy loam, daily precipitation 173mm, $\theta_0=0.30$)

As shown in table, in the condition of daily precipitation of 173mm the top soil of sandy loam and silty loam have ponding depth only 39.7 to 18.7 mm. The surface ponding time also only takes 4 to 6 hours. It will not cause the waterlogging disaster for farmland. In this kind of region to border the field for retaining more rainfall will increase the recharge to groundwater. In the region with heavy soil the attention of field drainage should be taken to avoid waterlogging.

CONCLUSIONS

The development of rainfall—flood utilization is an useful measure for increasing the effective use of rainfall water resources and for recharge groundwater. In certain degree it will mitigate the scarcity of water resources.

In the urban area the measures of conducting collected runoff from roof and ground to infiltration well and the measure of retaining greenland for infiltration can cut off flood peak discharge and can lighten the burden of flood protection of cities, as well as can increase recharge amount in flood season. This kind of rainfall—flood utilization system should be accepted into the planning of urban construction for active and practical extension.

In the plain suburb area with the top soil of sandy loam and silty loam, to use field for retention of runoff and to reconstruct the field drainage net system and river drainage system to "retaining and discharging double use system" can effectively increase field infiltration in flood season for recharge.

REFERENCES

- Latham, B. G. (1984) Rainwater Collection System; Literature Review, University of Ohawa, Institute for International Development and Cooperation.
- Hui S. B., Xie S. C. & Zhang S. C. (1992), "Analysis of Field Spacial Infiltration and Math—simulation Analysis of Utilization of Rainfall in Flood Season", Journal of Hydraulic Engineering No. 3, August, pp1—14.
- Thompson S. A. (1982) Reduction of Urban Runoff Through Economic Incentives: Boulder, Colorado. Water Resources Bulletin, Vol. 18, No. 1. pp 125—127.

Section 5

DOMESTIC SECTOR

Courtyard model of Catchment and storage water in the arid areas

Yang Xijing^①, Zhang Xingyou^②Wu Huairong^③

(Department of Geography, Lanzhou University, Lanzhou Gansu, P.R.China 730000)

Abstract

Lacking water is a great obstacle for economical and social development in the arid areas in western and northern China. By means of the calculating of catchment efficiency, the deducing of mathematical formulae and the cost-benefit analyses, it shows that the best way of solving human and domestic animals' drinking water problem in the arid areas is using the natural precipitation resources. The rationality of this avenue is also proved. Finally the problem is solved by using the courtyard model of catchment and storage water (Incl. mathematic model and arrangement plan).

Key Words: arid areas, Catchment and storage water, courtyard model, catchment efficiency, water cistern.

Lacking water is a general problem in the arid areas (the mean annual precipitation is less than 200 mm), the semi-arid (the mean annual precipitation is 200—450 mm) and the semi-humid (the mean annual precipitation is 450—600 mm) in the western and northern China, and also a great obstacle of the economical and social development in these areas, which includes 18 provinces (municipalities or autonomous regions) and 645 counties. On the vast arid Loess Plateau of the Northwest China, which lies at the interior continent, has the typical continental climate, a little rainfall, intensive evaporation (their aridity = 1.5—4.0), rough broken land, heavily gullied regions, mang mountains and a few rivers, and lacks surface water resources and groundwater resources (the dissolved solids content is 1—3g/L, some up to 5—7g/L), and has infertile soils and extensive cultivation, people live on rainy years only and have lower living standard. The problem has not yet been solved that residents and livestock have not enough potable water, and the policy of migration has been in consideration.

Considering people's abundant experience of digging cellars and storing water, having read some literature, basing on our observation and comprehension of the demonstration areas in the counties such as Yuzhong, Dingxi

① Professor. Department of Geography Lanzhou University

② Postgraduate. Department of Geography, Lanzhou University

③ Postgraduate. Department of Geography, Lanzhou University

and Tongwei, where Gansu Conservancy's researchers groups of rainwater exploitation in the arid areas have been, and searching some related data, We believe that it is an effective way of solving human and animals' drinking water problem and making people live and work in peace and contentment that people exploit the natural precipitation (mainly rainwater), through applying the courtyard catchment and storage water system (it mainly includes the house tiling, the courtyard ground and a water cellar), which is convenient to operate and easy to manage, feasible and economical, and simple in technology. Moreover, we have established different catchment and storage water courtyard models for different areas (Incl. mathematic models and arrangement plans), and promoted the development of the catchment agriculture and new type water resources (precipitation).

Authors would like thank Gaocheng, the director of Irrigation and Water conservancy department, Gansu Water Conservancy, and other members in the local Water Conservancy and Water and Soil Conservation departments for their helpness and support. In addition, all the basic data are the achievements of different pilot areas.

1. Establishment of Courtyard Catchment Mathematic Model.

Our thinking principles in designing work are costing minimal investment and gathering maximal rainfall. Therefore, it is our purpose to keep the optimum proportioning of the areas of underlying surface materials with using the optimum theory of system analysis.

Firstly, Establish an objective function that makes the cost Y lowest.

The objective function is

$$\min(Y) = \sum_{i=1}^n a_i s_i$$

Where a_i (yuan / m^2) is the unit area cost of the material i , s_i is its corresponding area (m^2), n is the total number of kinds of materials.

Secondly, Search the restrain equations of the objective function.

1.1 Requirement of the rainfall: The rainfall should meet the requirement of human and livestock's drinking water. Assumed that the population of a family is m , the water-use volume per head (Incl. its corresponding animals) is q (m^3), and the total water volume is Q (m^3). Because annual precipitation distribution is not even in the arid areas, and mostly from June to September. During this period, the drinking water can generally assured by the constructed water conservancy facilities (such as cellars and pools). We only want

to solve the problem in the rest 8 months.

$$Q = qm \times 8 \times 30 = 240qm$$

If expressed in precipitation, it is

$$Q = pb \sum_{i=1}^n A_i \alpha_i = pb \sum_{i=1}^n s_i \cos \beta_i \alpha_i$$

Where p is annual precipitation (m) in one area, b is an efficiency of considering the effective rainy season (April to October) and the loss of gathering water and others, and its general value is 0.8 or so. s_i and A_i are the surface area (m^2) and the projection area (m^2) of catchment ground respectively, α_i is the gathering efficiency of i (demical), β_i is the slope of its corresponding catchment ground (ratio).

1.2 Housing conditions: Courtyard Catchment must make use of the roofs (with the steep slope) which have several advantages such as clearance, hygiene and high catchment efficiency. Covering the roofs with concrete or machine-made tiles could not only meet gathering water, but also improve and beautify residents' living environment. But in the arid areas, people have lower income, and A , the area of structure, couldn't be too large (otherwise, the investment increases), and is necessary for people to live. Through our investigation and comparison, we think it is suitable that the value of A ranges from $5 m^2$ to $10 m^2$. Thus, the area of house roofs (Excl. shocks and simple sheds) equals $Am / \cos \beta_i$, the restrain equation is

$$\frac{5m}{\cos \beta_i} \leq S_k \leq \frac{10m}{\cos \beta_i} \quad (m \text{ is the number of the family})$$

1.3 The area of land; the Northwest China and Inner Mongolia are the vast sparsely populated areas (for example, on the Loess Plateau of Gansu, one person averagely has 15.5 mu land and 4.5 mu cultivated land). So the land for catchment and storage water has illimitable and the courtyard storing water could meet people's requirement if the ground is covered with materials of high gathering efficiency. But in the North China arid areas, the total land area ($s = \sum_{i=1}^n s_i$) should be limited for its high population density and land narrowness.

Then the mathematic model of the courtyard catchment is

$$\begin{cases} \min(Y) = \sum_{i=1}^n a_i s_i \\ Q = 240qm \\ Q = pb \sum_{i=1}^n s_i \cos\beta_i \alpha_i = pb \sum_{i=1}^n s_i \alpha_i \cos\beta_i \\ \frac{5m}{\cos\beta_i} \leq s_k \leq \frac{10m}{\cos\beta_i} \quad (1 \leq k \leq n) \\ s_i \geq 0 \end{cases}$$

Put the known numbers into the equations, adopt the simplicial method of linear programming and analysis the practical problem qualitatively, and we could get the optimum conclusions of the drinking water problem by means of the courtyard models in the different areas.

2. Application of the Courtyard Catchment Model.

We take the arid Loess Plateau, central Gansu as an example to discuss the application of this model. The following is a group of testing data under the condition of annual precipitation 300 mm. The key to the question is to verify that the gathering efficiency of different underlying surfaces is affected by the qualities of materials, the ground slope, the intensity and the volume of rainfall on the spot and other factors. The catchment efficiency is given by the following formula:

$$\alpha_0 = \frac{\sum_{i=1}^n p_i \alpha_i}{\sum_{i=1}^n p_i}$$

Where α_0 is the mean catchment efficiency, p_i is the rainfall volume of each time, α_i is the gathering efficiency, which is also given by the empirical formula:

$$\alpha_i = 1 - \frac{c}{p^a I^b}$$

Where p is the rainfall of one time, I is rainfall intensity (mm / min), a, b

and c are the physical geographical parameters, which is given through least square method and multiple-correlation analysis.

The calculated α_0 is verified by the observed data in practice, and theory coincides with practice. The characteristic values are summarized in the following table:

catchment characteristic values of different underlying surfaces
in the typical places in the arid areas on the Loess Plateau, central Gansu

characteristic value	concrete	concrete	plastic film weed and mud	cement tile	machine-made tile	3:1 plant ash soil	rammed sedentary soil	rammed sedentary soil
thickness(cm)	3-5	5	3-5	2-3	2-3	10	10-15	10-15
place	Xifeng	Yuzhong	Xifeng	Yuzhong	Yuzhong	Tongwei	Yuzhong	Xifeng
slope(ratio)	1:9	1:50	1:9	1:3	1:3	1:10	1:50	1:9
efficiency(decimal)	0.79	0.58	0.40	0.79	0.51	0.30	0.17	0.27
runoff volume (m^3 / m^2)	0.237	0.174	0.120	0.237	0.153	0.09	0.051	0.081
cost (yuan / m^2)	3.9	3.9	3.3	3.7	4.0	2.7	1.2	1.2
cost (yuan / m^3)	16.5	22.4	27.5	15.6	26.1	30.0	23.5	14.8

The data in the table indicate that, concrete, cement tile and rammed sedentary soil gathering ground surfaces have less cost. But the rammed sedentary soil gathering ground is only assistant for its short service life and no hygiene, and the concrete gathering ground of the slope of 1:9 is not suitable. Therefore, we choose cement tiling and concrete ground of the slope of 1:50 as the courtyard underlying surface, then n in the model equals 2. In addition the average consumptive use of water per head per day (Incl. animals) is 15 litres according to the regulations and investigation. Then the data of a family of 5 are the following:

$$n = 2, \quad q = 15L = 0.015m^3, \quad m = 5 \quad p = 300mm = 0.3m$$

$$\alpha_1 = 0.58 \quad \alpha_2 = 0.79, \quad \beta_1 = tg^{-1} 1 / 50 \quad \beta_2 = tg^{-1} 1 / 3, \quad b = 0.8$$

$$k = 2, \quad a_1 = 3.9(\text{yuan} / m^2) \quad a^2 = 3.7(\text{yuan} / m^2)$$

The model would be:

$$\begin{cases}
\min(Y) = \sum_{i=1}^2 a_i s_i = 3.9s_1 + 3.7s_2 \\
Q = 240qm = 240 \times 0.015 \times 5 = 18 \\
Q = pb \sum_{i=1}^2 s_i \alpha_i \cos\beta_i = 0.3 \times 0.8 [0.58s_1 \cos(\text{tg}^{-1} 1/50) \\
+ 0.79s_2 \cos(\text{tg}^{-1} 1/3)] = 0.139s_1 + 0.180s_2 \\
\frac{5m}{\cos\beta_2} \leq s_2 \leq \frac{10m}{\cos\beta_2}, \frac{5 \times 5}{\cos(\text{tg}^{-1} 1/3)} \leq s_2 \leq \frac{10 \times 5}{\cos(\text{tg}^{-1} 1/3)} \\
\frac{5 \times 5}{0.95} \leq s_2 \leq \frac{10 \times 5}{0.95}, 26.3 \leq s_2 \leq 52.6 \\
s_1 \geq 0
\end{cases}$$

To solve these equations and get: $s_1 = 64.5\text{m}^2 \approx 65\text{m}^2$, $s_2 = 52.6\text{m}^2 \approx 53\text{m}^2$, $\min(Y) = 3.9 \times 65 + 3.7 \times 53 \approx 450$ (yuan). If more different underlying surfaces materials are applied, it is more comprehensive to put the data into a computer to solve the problem through the optimum calculation.

3. Discussion on The Storage Water Cistern

Gathering rainfall is the prerequisite, and storing it for drinking is the purpose. In the arid areas, people's common storing water models are cisterns and concrete pools. Considering the experience in Lintao County, Gansu, we think, the thin shell concrete cistern is mostly economical and rational, and could be used extensively. Because it has less cost than that of concrete pool (a thin shell cistern costs 8 yuan / m^2 , a concrete pool 10 yuan / m^2), has more infiltration proof than the traditional cistern (earthy), needs simple technology save labors, and is easily managed, and has reliable hygiene. After some experience, many constructed cisterns could be improved (So has been done in Cheng cheng county on the Weibei Loess Plateau, Shaanxi since 1958).

A thin shell concrete cistern consists of a cistern mouth, a cistern top (arc-cambered), a cistern barrel (round), a inlet pipe and a deposition and purification pool (fixed or temporal) and others [see Fig.1.]. The thin-shell cistern of the sizes indicated in Fig.1, could store water of 20m^3 and cost 160 yuan. Although our designed family water use is 18m^3 , in the view of long-term benefits (in case of the loss of storage and the unexpected water use), we suggest a family of 5 build a thin shell concrete cistern of 20m^3 for storing drinking water with more high assurance rate

4. Courtyard Arrangement of Catchment and Storage Water

Now, we still take the arid Loess Plateau as an example (such as Beishan

in Yuzhong, Gansu) to give explanation: the upper analyses and calculation have showed that a family of 5 should build a collection and storage system, which consists of a concrete courtyard surface, the area of 65m^2 , the thickness of 5 cm and the slope of 1:50, a cement tiling of the thickness of 2—3 cm and the area of 53m^2 (the projective area equals 50m^2) and a thin-shell concrete cistern with a storage capacity of 20m^3 , and totally occupies a piece of land of 115m^2 , and costs 610 yuan, average 122 yuan per head. The cost is equal or less than that of the current engineering measures to solve the drinking water problem, so the plan is feasible and practical.

Further explanation is that, the collection and storage system only occupies less than half of the total area of a common courtyard ground surface ($0.35\text{mu} = 233\text{m}^2$), and the rest land could be used to build livestock sheds and storage rooms, and grow vegetables and fruit trees to develop garden economics in the idle land.

5. Discussion of Other Problems

This paper has given the gathering and storing courtyard model of solving human and animals' drinking water problem. Furthermore, there are many other related problems to be further researched: for example, the thought of exploiting rainfall to develop the agriculture in the arid areas is similar, except that the cost of concrete surfaces is too much. Considering the abroad experience, we should pay attention to the research of the qualities of new type gathering materials—sealing up the soil pores or making the soils moisture repellent with some chemicals (such as sodium salt), flattening and weeding the land, spraying two layers of mineral pitch (one seals up the soil pores, another prevents the land surface from weathering), melting the granular paraffin wax with sunlight to seal up the soil capillary, covering the plastic film on the soil with sand or stone and others, and increasing gathering benefits, and building gathering ground. In addition, the characteristics of precipitation and the assurance rate of gathering in the arid areas, the infiltration proof of storage barrels and the steadiness of water quality and so on are also worth discussing and researching.

The courtyard gathering and storing water model could be suitable in the extensive areas, and it has an disadvantageous factor that the investment would rise with the decrease of precipitation and the increase of gathering area. In the areas of annual precipitation less than 150 mm, the model is generally not suitable. Thus, in the Southern Xinjiang of annual precipitation less than 70 mm, and Hexi Gallery annual precipitation, 50—150 mm, there is no or a little runoff and drinking water relies on melted snow water, springs,

Karez and pump wells. In the Gobi Desert, Inner Mongolia of annual precipitation less than 100 mm, domestic water use only comes from ground water of the wells and springs. In the arid North China, annual precipitation is 500 mm or so, the courtyard model would be worthy to some extent. On the arid Loess Plateau in Northwest China, annual precipitation mainly ranges from 300 mm to 400 mm, its extensive country is the most suitable land for the courtyard model.

Reference

- [1] American Nation Science Academy (compilers), Tang Dengying et al. (translators). 1979. Technology for water collection and conservation in the arid areas. Beijing: Agriculture Publishing House (in Chinese).
- [2] Gansu Cartographic Atlas Compiled Office. 1975. The map of Gansu, P.R. China (groundwater special map). Lanzhou (restricted publication in Chinese).
- [3] Luo Mingyu. 1988. On the development and exploitation of water resources in the arid areas of Gansu. Gansu Water Conservancy and Hydroelectricity Technology, No.3. (in Chinese).
- [4] Luo Mingyu. 1990. Studies on the rainwater exploitation in the arid areas of our province. Gansu Water Conservancy and Hydroelectricity Technology, No.1. (in Chinese).
- [5] Northwest Normal University and China Cartographic Publishing House (editors). 1984. Chinese physical geographical Atlas (Chinese annual aridity map). Beijing: China Cartographic Publishing House. (in Chinese).
- [6] Shahxi Science and Technology Information Institute. 1983. Arid and semi-arid agriculture science and technology data selections in China, v.1. (in Chinese).
- [7] Sun Fuping. 1990. Rural simple project for human and animals' drinking water—the thin shell concrete cistern. Gansu Water Conservancy and Hydroelectricity Technology, No.1. (in Chinese).

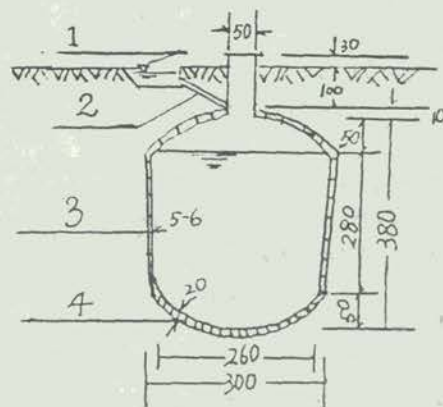


Fig.1. A thin shell concrete cistern (unit:m)

1. disposal and purification pool
2. inlet pipe
3. cast-in-stu concrete
4. Larring and stone concrete

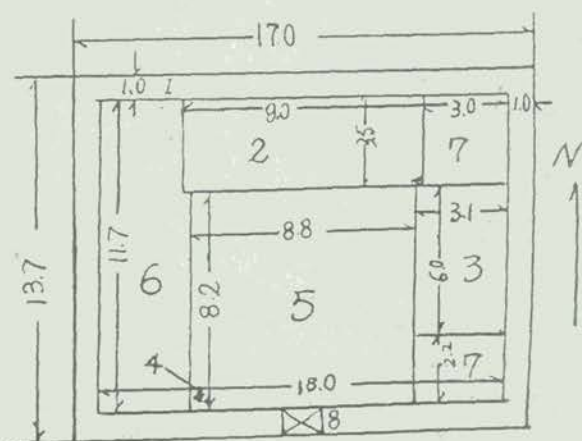


Fig.2. The arrangement plan of gathering and storing courtyard (unit:m)

- | | | |
|--------------------|--------------------------------------|-----------------|
| 1. barrier wall | 4. water cistern | 7. simple sheds |
| 2. principal rooms | 5. concrete courtyard ground surface | 8. great gate |
| 3. side rooms | 6. idle land | |

THE CATCHMENT AND UTILIZATION OF YARD RAINWATER IN ZHUANYAOGOU VALLEY

Li Hongjian Liang Sibao

(Institute of Loess Plateau Geography, Shanxi University, Taiyuan, 030006)

Abstract

As one of the main measures of domestic water supply and water and soil conservation, we encourage the farmers to build the water cellars in their yard to catch and use rainwater in Zhuanyaogou valley. The cellars that have been built are arch cuboid, with a volume of 15 to 25 m³, and divided into two kinds: the mixed and the separated. The catchment at present is mainly used for washing clothing, raising livestock and watering vegetables. The chemical analysis of the cellar water for drinking shows that its quality reaches the drinking water standard. The capacity of the cellars should be increased in the future.

The Zhuanyaogou valley is located in Hequ, a County in the northwest of Shanxi Province. It is a small tributary direct to the Yellow River, with an area of 27.8 km² and 15 administrative villages. It is one of the eleven experimental management stations of the state key project—Comprehensive Management of the Loess Plateau Region during the period of the Seventh Five-Year Plan (1986—1990). The area is typical of loess ridge, hill and ravine. The average annual precipitation is 447.5 mm with significant annual and seasonal variations, and the amount of July and August takes up over 60 percent of it. These geomorphic and climatic conditions lead to severe water loss and soil erosion. The tapping condition of water resource is not good, and a few small springs supplied by rainwater often fail to flow in the spring and winter in drought year because of devastation of the vegetation. So the problem of domestic water supply is becoming worse.

The history of domestic water supply

The area was exploited relatively late. The way of cultivation was extensive; the level of economy and culture lagged behind. There was no traditional custom of rainwater catchment in this area, since most villages are located in loess ridges, loess shoulders and slopes, the domestic water for human beings and domestic animals and fowls used to be carried by farmers and domestic animals with water pails from the springs at the bottom of gullies. With the growth of population in this area and the rise of its people's living standard, especially with the unprecedented development of rural economy due to reform and open door policy, the demand for water was greatly increasing. The water supply became a burden of farmers, and also a limiting factor to further decel-

opment of aquaculture, animal husbandry and courtyard economy. At the same time, more and more coal mining caused damage to water—resisting layer, which made a lot of small springs exhausted. Facing this kind of natural environments and social backgrounds, while the state key project was being carried out where, we made a plan to construct water cellars in farmers' yards and to catch and use rainwater as one of the main measures of conserving water and soil, and developing courtyard economy. After several years practice, the desire of the farmers to build the cellars is becoming stronger and stronger. For example: since the first water cellar was built in 1988, 30 cellars have been completed by the end of 1994, which accounted for 30 percent of local families. All of the households that have built their new houses in recent years have constructed water cellars in their courtyards with an increasing standard and a bigger volume. The cellar water has become main resource of domestic water supply. Now a total of 200 water cellars have been built in the valley and have brought about economical, social and environmental benefits.

The storage and utilization of rainwater in the yard

The collecting system of rainwater consists of three parts—catchment, transportation and store.

Rainwater catchment comes from house roofs and some part of house yards ground. The house roofs in this area are single—inclined plane with a slope of 3 to 5 degrees. The catchment area of a roof is about 21×4.5 to 5.5 m^2 , and a yard ground 21×5 to 7 m^2 (which takes up 30 percent of all yard ground, the left is used for vegetables, fruit trees planting, etc.). The total catchment area of a yard is usually over 200 m^2 . The catching period is from the last ten—days of June to the first ten—days of September, and heavy rains are mainly between July and August. According to the precipitation data (1954—1973) provided by Hequ County Weather Station and the data that we collected on the spot from 1988 to 1994, the mean precipitation during the period of rainwater catchment is over 250 mm (the maximum is 320 mm in 1992). Calculated on the basis of a runoff of 200 mm, the mean runoff of a yard can reaches over $35\text{—}40 \text{ m}^3$.

The water from the roof enters water cellar through two different processes. One is through the drain pipe of the roof to the water cellar and the other is to the yard ground and then enters the water cellar. The water from the yard ground enters the cellar directly or through simple filtration.

The water cellar is the main body of rainwater collecting system. Most cellars that have been built so far are arch cuboid, which are 4 to 5 m long, 2 m wide and 2.5 to 3.5 m deep. The height from the vault to the yard surface is 0.5 m. Their volume is about 15 to 25 m^3 . The water cellar is made of bricks and plaster, and its inner wall is covered with cement mortar. According to the way how to store water, the cellars are divided into two kinds: the

mixed and the separated. The former has only one big cellar for both roof and yard ground catchments, and the latter consists of two small cellars: one is for roof catchment, and another is for yard ground catchment; the cellar for roof catchment is also used to store the spring water fetched from the bottom of gullies. Mixing the spring water with the roof catchment can improve the quality of the cellar water.

For the separated cellar, the roof catchment in one of the two small cellars is mainly used for drinking and the water in another small cellar is used for washing clothing and raising livestock, watering vegetables and fruit trees to develop courtyard economy. The area is abundant with light and heat resources, but because of the lack of water the farmer's courtyard was in unused condition. Since the cellars have been built, the households plant vegetables or fruit trees in their yards. This not only provides the farmers with variety of vegetables but also improves the environment, and reduces water loss and soil erosion.

For the separated cellar, the roof catchment in one of the two small cellars is mainly used for drinking; the water in another small cellar and in mixed cellar is used for washing clothing and raising livestock, watering vegetables and fruit trees to develop courtyard economy. The area is abundant with light and heat resources, but because of the lack of water the farmers' courtyards were in unused condition. Since the cellars have been built, the households plant vegetables or fruit trees in their yards. This not only provides the farmers with variety of vegetables but also improves the environment, and reduces water loss and soil erosion.

The physical and chemical quality of the drinking water

The transparency of catchment is relatively poor. It appears subtranslucent or turbid usually, because rainwater dissolves the soil and dust in the course of its runoff. Transparency depends on the solidness of the materials that were made of the roof and the yard ground and the cleanness of their surfaces. After several days' sediment, or added a little amount of lime, the catchment of the cellar will become transparent. The catchment for drinking has no peculiar smell and rotten taste.

Except for a few small coal mines in the valley and nearby region, there are no industrial enterprises there, so the rainwater has not been polluted. We analysed the chemical elements of the cellar water that the farmers have drunk for a few years, and compared the results with those of the spring water. The results (Table 1.) show: there is no significant difference in cations in the cellar water and the spring water, and Ca^{+2} or Mg^{+2} is given the first place. Of the anions, SO_4^{-2} is given priority, and then HCO_3^{-1} in the cellar water; however, HCO_3^{-1} is the principal element in the spring water. The cellar water is classed as $\text{SO}_4\text{HCO}_3\text{—CaMgNa}$, and the spring water as $\text{HCO}_3\text{—MgCa}$. Ac-

cording to the PH value, total hardness, mineral degree, and fluoride, the cellar water for drinking reaches the drinking water standards promulgated by public health administration.

Table 1. Drinking water analysis in Zhuanyaogou Valley* (mg/l, except PH)

Items NO.	K ⁺ +Na ⁺	Ca ²⁺	Mg ²⁺	CO ₃ ²⁻	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	PH
1	38.0	56.9	25	0	105	156	24.8	7.9
2	17.9	25.7	10.9	0	106	125	14.5	7.4
3	14.5	29.1	22.5	0	211	101	7.8	7.5

Items NO.	Total hardness	Mineral degree	Fluoride	water type	Note
1	245	347	0.19	SO ₄ HCO ₃ -CaMgNa	cellar water (with lime added)
2	109	265	0.16	SO ₄ HCO ₃ -CaMgNa	cellar water
3	165	260	0.70	HCO ₃ -MgNa	spring water

* By the Monitor center for Water Environment, Shanxi Province: total hardness is based on the amount of CaCO₃.

Suggestions for further development

The catchment of yard rainwater paves an effective way for domestic water supply in semi-arid region. The northwest of Shanxi is a scarcely populated area, the farmers' yards are relatively larger, and so is the catchment area. Investing about 1,000 yuan to build a water cellar in their yards, the household can mainly resolve the problem of domestic water supply. Because the property right of the cellars belongs to the farmers themselves, and they are convenient to use, the farmers investing desire is much higher than that of collecting money from them to construct other small water engineering works. Now whether a family has a water cellar or not has become one of the criterions of judging its living standards. The larger the water cellar is, the richer the family appears. Early in 1970's in order to solve the problem of domestic water supply, the government allocated funds to build several small water engineering works in the valley, but due to shortage of water resource and bad management, soon they all become failure. As compared with this kind of investment, the result of aiding farmers financially to build the water cellars should be much better. For this reason, we suggest that the government should adjust the poli-

cy, and give farmers proper financial aid to popularize the water cellars in northwest of Shanxi Province.

At present the catchment rate of yard rainwater is relatively low, and the construction of water cellar is in lack of scientific guides.

Its volume is relatively small. Because the materials used are not solid enough, the farmers only store the water to 80 percent of the cellar's volume for fear that it should be damaged. Consequently a great deal of yard rainwater flows outside the yard. So the scientific guides should be given in building the water cellars. In order to keep the rainwater as much as possible, increasing the thickness of cellar wall, expanding its capacity or building more cellars is the main task in the future. At the same time the models of rainwater catchment should be set up in order to utilize rainwater from not only courtyard but also gully slope, road, thrashing ground and so on. This will play a great role in water and soil conservation, improvement of ecological environment and development of economy in the Loess Plateau region.

In addition, the protection of cellar water quality should be done, especially for edible water. The separated storage of catchment should be encouraged and the surface of catchment area should be kept clean during the rainfall season. It is necessary to add a sedimentation tank or filter pipe to purify the catchment before it enters the water cellar and to monitor the quality of the drinking water.

REFERENCES

- Weibang zhang . 1992 . Management of the Loess Plateau region. Beijing : Science Press.
- Renqiong Su . 1990 . Water resource problems and their countermeasures in the Loess Plateau region. Beijing : China Science and Technology Press.

Rainfall Collection to Develop Courtyard Economy

Wang Wenyuan, Yang Luhua & Zhao Lianying

(Agricultural University of Hebei, 071001)

Abstract

This paper describes the basis of the courtyard economy development, and indicates that to develop courtyard economy is an important way for people from poor to rich in poor district. to collect rainfall is a major guarantee to develop the courtyard economy in water resources crisis area. After that, authors put forward a relationship among the rainfall volume, catchment area and courtyard economy scale, found a relevant mathematical model for referring by users.

Keywords: Courtyard Economy, Rainfall Collection, Rainfall Collection Efficiency

Being a big agricultural country, the amount of farmers is above 80% of total population in China. Improvement on the farmer's living standard is a major sign of national economy development sound. Being additional link to agricultural production, being an effective source of farmer's income, developing courtyard economy has important realistic and historic significance in China, especially in an outlying district where there are less people and more land.

1. Courtyard Economy Is a Significant Way by which People Become Rich in Poor Area.

1.1 The Courtyard Economy's History

Courtyard economy has been developed on the base of courtyard plantation and breeding. In thousands of years, the land in the front of house and courtyard has been utilized for plating vegetable, fruit tree, breed livestock such as chicken, duck, pig, sheep in north county of China, which product is more for themselves than for others. This type is not courtyard economy. In 80's, commodity sense being enhanced, village and town's business developed very fast, courtyard, the small land, takes change rapidly, steps into commodity production from self-supporting production. Productive expert who are quick-witted, have rich information and know-how, exploit their about 200-500m² courtyard in high effect. Guided by technology, plant product staggered busy market, they get huge benefit by seasonal price difference. Some become a dab of shed vegetable, some become mushroom king, some become grape professional household, even some cultivate rare medicinal materials, such as ginseng and American ginseng whose the benefit is more than one of others. The product of courtyard owns a part of the market, so courtyard plantation becomes into courtyard economy.

1.2 Courtyard Economy is a Significant Way by which People Become Rich in Poor Area.

The poor area general lie in outlying remote district. Bad production condition and lag technology, but less people more land, large courtyard, rich labor, are suitable for developing

courtyard economy. Because of lag economy, it is difficult to invest largely into agricultural production. Courtyard economy needs small fund, high product by low invest, develops step by step, simulates fund, lays a foundation for agricultural development finally.

Courtyard economy may add farmer's income remarkably. According to material of Heilongjiang province, if the courtyard area is 200 m², net cost of shed cucumber being 11.3 yuan RMB per square meter, the total income reaches 2260 yuan RMB; staggered busy market, net cost of shed grape being 5-7 yuan RMB per square meter, the total profit is 1000-1400 yuan RMB. In Hulin county of Heilongjiang province, farmers have been planting ginseng in their 134 m² courtyard, got 2345 yuan RMB net profit, net profit is 17.5 yuan RMB per square meter. According to statistics figures of Neimenggu autonomous region, the amount of peasant households who have exploited their courtyard has reached 36,000, make up 40 percent of the total amount of peasant households who have potentiality to develop courtyard economy, and emerge a rapidly increasing trend. A great plant kinds are suitable for planting in courtyard, on the condition that plant kind is choosed according to local region, the net profit must be considerable.

Not only add farmers' income, but also use the scatted plots of unutilized lands, make use of elder and weak labor, utilize spare time in winter season or busy season, and make full use of land resources, labor resources, even time resources, plus good intensive cultivated tradition, economic benefit, social benefit, ecological benefit all is significant.

2. Rainfall Collection Guarantees Courtyard Economy Development in Water Deficient Area.

Water resources is limited in China, especially in north China, for example, water resources deficient is nearly one third in common year in north China. So improving the water resources effective utilization ratio is a strategy measure, particularly the direct utilization of rainfall is more valued than even. Courtyard economy is nothing without water, especially plantation, water resources is restricted factor to get high yield. Water resources condition being worse in poor area, whether building the ground irrigation project or drawing ground water need much fund, it is difficult to carry out in poor area quickly. And by catching, collecting and storing projects, surface runoff of rainfall being stored, by water supplying system, water is supplied for farmers, which rainfall costs greatly. If drawing the ground water transformed by rainfall, it adds not only water cost, but energy consumption, which is more difficult in the outlying or mountain region where hydrology and geology condition is complicated. For instance, a 40-60t/h water-cut well costs 60,000-80,000 yuan RMB in the northwest plateau of Hebei province, which farmers can't bear in poor area. No water, no courtyard economy, so collecting rainfall by simple catchment system which founded by themselves, supplying courtyard economy, is reliable method which solve irrigation water and people and livestock drink water. Collecting rainfall fallen into roof and storing in cellar in the courtyard, supplying for drinking water has rich history in water resources deficient village of Hebei and Shanxi province. Popularize the simple collecting and storing rainfall project, it can solve the water demand of courtyard economy in water resources crisis area. In spite of small rainfall, but amass rainfall comparatively, the amount in rain season is 70-80 percent of the total amount in whole year, and strong rainfall intensity, it makes possible to catch the rainwater fallen into roof and yard. It was analysed that 30m³ rainfall water can be collected per year in 100m² building roof under circumstance that rainfall volume is 500 mm, can guarantee that water demand of 150-200m² courtyard crops. If saving water irrigation method, such as plastic film covering, is taken, the

area still is more large. It is to say that rainfall collection and stored by every household can ensure the water demand of courtyard economy.

3. Discussion about Some Technological Problems on Rainfall Collection to Develop Courtyard Economy.

3.1 Relationship between Catchment Area and Courtyard Economy Scale.

Different region, different rainfall volume water; different crops, different demand; and different project standard, different rainfall collection efficiency, (the percent of collecting rainfall volume to total volume in the same area), plantation area in the courtyard can be determined according to local meteorology, crop, farmer's financial condition. The following is a referring formula for determining planting area.

$$\Omega = P \alpha A / I \quad (1)$$

where

Ω ----- the plantation area in courtyard (m^2);

P -----the average rainfall(mm);

α -----the water collection efficiency (%);

A -----the crop area(m^2);

I -----the water demand of crop(mm).

In the above formula, the area of water collection mainly refers the area of the house roof and courtyard in the front of house, which can be determined according to general farmer's household. The rainfall volume can be got from meteorology agency, the crop water demand can be referred to relevant experiment result. The key problem is to determine collecting water efficiency which needs investigation on water projects. Figure 1 indicates the influences on water collection area by water collection efficiency. Water collection efficiency is relevant with rainfall intensity, rainfall volume and loss in the process of catching and collecting rainfall, it should be determined by experiment and investigation. The relationship is indicated by the following example which grape and vegetable is planted in Huailai county of Hebei province.

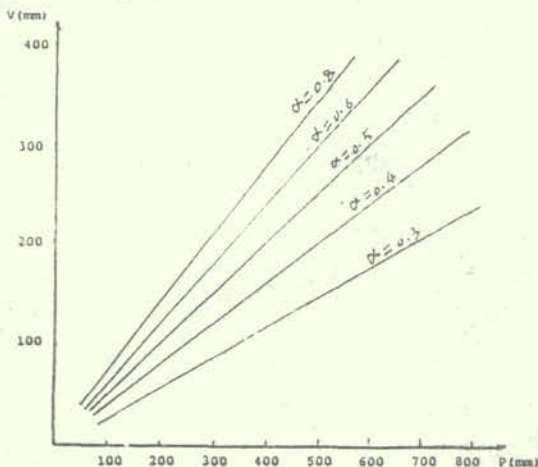


Fig. 1 The Relationship Among Water Accumulation Efficiency Water Collection Area and Rainfall Volume

The average rainfall is 431 mm, the total area of household is general 400-500 m², among them the area of house roof is 98.0m², the yard area in the front of house is 50m², total area is 148m², grape water demand is 450 mm, grape can directly utilizes the rainfall water half of its total water demand in the grape growth period, so water supply only 225 mm, let water collection efficiency as 0.6, 38.3m³ water is obtained in perennial year according to formula 1, 0.225 m³ water is required per square meter, so 170.1 m² can be figured out as plantation area. The shed cucumber water demand being 500 mm, let water collection efficiency as 0.6, total collecting and storing water volume is 59.8m³, plantation area is 117m². If plastic film covering or drop technology can be adopted in the shed, the area can expand to 1.5-1.8 than original.

3.2 Arrangement Form of Water Collection System in the Courtyard Economy

Because the courtyard and house structure vary, the rainfall collection water project should be designed and build according to concrete conditions. As a key project, storing pool is particularly valued which is designed not only sturdy and durable but also convenient using and maintain. Build material should be drawn on local resources in order to save expense. Figure 2 is typical plane of arrangement of the water collection project in the courtyard. Figure 3 is structure sectional drawing for referring by users.

To sum up, rainfall collection to develop courtyard economy is important method, which increases farmer's income, helps people rich in poor area, makes full use of water resources by improving rainfall effective utilization ratio. Although courtyard economy is small to a household, it will play a part not to be ignored in changing the village look.

Reference

1. Shuren Kang. 1990. Manual on Courtyard Economy Technology. Chinese Agricultural Society.
2. Zhizhong Dong. 1993. Expand and Apply of Drip Irrigation Technology in Village. Sprinkle Irrigation. No.2.
3. Irrigation agency of water conservancy bureau. 1989. Analysis on the Different Irrigation Methods in Plastic Shed. No.2.

IMPROVED ROOF RAINWATER HARVESTING IN PRIMARY SCHOOLS

Niemi Tapio

ABSTRACT

The article describes the development of Roof Rainwater Harvesting (RRWH) technology in 72 primary schools by the Nakuru and Nyandarua Intensified Forestry Extension Project/FINNIDA in Kenya.

The design considered the demands of a school tree nursery, quality and quantity of drinking water and water for washing hands.

The design was based on the availability of local materials, appropriate technology, the level of maintenance and operation communities can sustain, high water quality and prevention of mosquito breeding places.

The RRWH-system was optimised on the tank form and size, material use, rain guttering and piping in a rainfall area of 570 - 1,200 mm/yr, with a special emphasis on the water intake system. Achieved Roof Rainwater Harvesting Coefficiency (RRWH/C₀) is > 80 of the annual rainfall up to a 75 m long building or 526 m² effective roof catchment area.

The standardised masonry tank has the effective capacity of 27 m³ and it fills 9 times/yr with a water turn-over of 5 weeks.

The cost of water is USD 0.94/m³ by a 2 % capital recovery rate and USD 0.33/m³ by 0 % interest rate for 30 years, including community participation (17 %) and project overheads (12 %).

Main benefits are 1 litre of potable water for 500 people/270 school days/yr and production of 7,000 tree seedlings/yr for 30 years. Facilitation of improved environmental education of children and other community members.

INTRODUCTION

The RRWH-development was done through the Nakuru and Nyandarua Intensified Forestry Extension Project (started 1990), locally known as *Miti Mingi Mashambani* (MMM) project, which is funded jointly by the Finnish International Development Agency (FINNIDA) and the Government of Kenya. The implementation of the project is carried out through the Ministry of Environment and Natural Resources/Forest Department/Forestry Extension Service Division. The long term development objective of the MMM-project is to place the supply of essential tree products on a sustainable basis and of stabilizing and improving the rural environment through rural afforestation. The immediate objectives of the project include the development of a competent, effective and cost-effective forestry extension service which, in turn, will set in motion a self-help forestry and wood conservation by farmers, self-help groups and institutions. (Project Document, 1990).

In the project strategy formulation primary schools were found to be very important, based on the fact that in Nakuru District about 50 % of the population are children under 15 years of age. (Nakuru, District Development Plan, 1989-1993). Further realizing, that it is the same school children who will be the environmental key-players in near future, there was an obvious need for the development of a intensified school programme.

Based on the MMM-project's base line socio-economic study (Pehu, E. and Smith Saulniers, S. 1991) and field experience in primary schools, the availability of water was found to be one of the major problems in general and in particular in the school tree nursery operation and tree planting.

Field studies further revealed, that most of the 380 primary schools in Nakuru District had galvanized corrugated iron sheets (GCI) as roofing material with an estimated average roofing size of 1,500 m²/school, but only with a very low utilisation rate for water harvesting. Different type of water tanks were found to be existing in the school premises, but unfortunately with one major problem; there was no water because of an ineffective water intake system.

On the other side, the rainfall conditions in Nakuru District with an average annual rainfall of 862 mm/yr and 125 rainy days/yr, with no month without a rain (Atlas of Kenya, 1970) were found to be fairly good for the construction of RRWH-systems.

DEVELOPMENT CRITERIA

Target

The overall target was to assist school children and other school staff with safe drinking water and water for washing hands and to facilitate environmental education through improved tree nursery operation.

General guidelines

MMM-project's Technical and Management Committee (TMC) defined some guidelines to be followed in the design and concept development of the planned RRWH-system which include:

- The water is to be used as drinking water as well as in the school tree nursery activities. The water quality should be targeted to fulfil the WHO standards for cistern waters of 10 coliform/100 ml (WHO, 1984).
- The system should form a permanent infrastructure for the next 30 years and be low-cost in operation and maintenance.
- Construction of the system should include elements of community participation.
- Use of locally available materials.
- Design should be based on local technology.
- Consider the level of infrastructure in the project area as hardware stores, quarries, roads, transportation and the type of existing roof catchment area of the school buildings.
- Design should be such, that it is controlling mosquito breeding by eliminating suitable habitats.

OPTIMISATION OF THE RRWH-SYSTEM

Finding an optimum size and quality for a RRWH-system is not straightforward, because optimisation is a target oriented activity within a given frame of limitations. The size and quality is critical in the economic design. The optimum between the demand rate, required water harvesting area and the prevailing rainfall pattern at a certain level of quality requirements was in this example looked after by asking:

- 1) How much water is needed and from where and when it should come?
- 2) What are the financial limitations?
- 3) How to optimize technically the selection and use of materials under an ideal proportion and size of the storage cistern?

Demand and Supply

The size of the RRWH-system was set to provide 1 litre water for drinking and washing hands for 500 people/day in 270 days/yr and sustain the irrigation of a school tree nursery of 2,000 tree seedlings in the drier period (October-March) and 5,000 tree seedlings in the main rainy season (April-September). Table 1.

Material selection

The basic locally available building materials for the tank construction were 11 m³ sand, 183 m building stones (6" x 9") and 11 m³ hardcore of hard type. GCI-sheets were used for rain gutters. Half drums and galvanized iron water pipes were used to convey the water by gravity into the water tank. School communities contributed 50 % of the required basic materials. MMM-project provided all other needed materials.

Proportions and size of the water tank

The effective height of the tank (208 cm) was determined by the type of roofing in school buildings, the workability of the quarry stones (8 layers), placing the tank bottom at the ground level and the position of the overflow pipe. (Figure 2). The round shape was calculated to be the most economical in the volume/cost design. (Figure 3). Round water tanks are common in the area and well accepted by the local community. The tank has the inside diameter of 412 cm and an effective capacity of 27 m³.

Size of the piping

Different sizes of water pipes (3/4", 1" and 1 1/4") were tested under field conditions. The galvanized A-class water pipe (6 m x 1 1/4" x 16 kg) was found to be the most suitable considering the effectiveness (RRWH/Co), price, durability, maintenance and workability.

Type of rain gutters

New type of rain gutters were looked after, because of the imminent need in the project area to improve the rainwater intake system into water tanks. In the new system the rain gutters were tailor-made at the construction site out of GCI-sheets (3 m long x 88 cm wide x 28 gauge). (Figure 4). The GCI-type of rain gutters are having following properties:

- A 9 m rain gutter unit was found to be the most suitable in workability, handling and fitting into the roofing with a good slanting of (20 cm/900 cm = 2.2 %). Rain gutters can be extended up to 15 m of length.
- They can also be easily fixed in roofings without the help of fisher boards.
- They are strong, flexible, straight, water proof, easy and cheap in maintenance, big enough not to overflow by heavy rains and aesthetically nicely fitting.
- The way the gutters are fixed into the buildings is additionally strengthening the roofing of the buildings against heavy winds.
- They have a good self cleaning property and dry fast after a rain and are easy and low-cost in maintenance.
- They are not corrosive and maintain the water quality.

Model to adjust the optimum length of rain gutter units and the optimum size of a roof catchment unit within a rainfall range of 570 mm- 1,460 mm (Figure 5).

Explanations to Figure 5.

Condition: A-point is in Nakuru Town at Pangani Primary School. The underlying figures for the RRWH-unit are: one 60 m x 1 1/4" pipeline connected with 5 rain gutter units (@ 10 m) harvesting water from a 175 m² effective catchment area from a 50 m building. Gravity difference is 1.0 m between the bottom level of half drums and the tank inlet point of the pipeline. (Figure 1 and Figure 6).

Output: the constant maximum rainwater harvesting capacity is 0.4 l/min/m² or absolute 70 l water into the tank/min/one piping line. Puffer: 5 x 100 l = 500 l/every rain more than 0.4 l/min/m². When the rainfall is 0.4 l/min/m² or less then RRWH/Co is constantly more than 95. (Figure 7).

Y	Rainfall mm/yr
X ₁	Length of one rain gutter unit (m)
X ₂	Size of one roof catchment area unit (m ²)
X ₃	Length of the building (m). Roofing width of 3.5 m is used, instead of 4 m, when counting the effective size of the roof catchment area.
R	Curve of annual rainfall
F ₁	Limit for the shortest rain gutter (3 m) when using GCI-sheets of 3 m length.
F ₂	Limit for the shortest rain gutter (6 m) in Nakuru conditions when using GCI-sheets of 3 m length.
F ₃	Technical limit for longest rain gutter unit (15 m)
P ₁	Rainfall in Nakuru town 862 mm/yr. Average of 56 years. (Atlas of Kenya, 1970)
P ₂	Rainfall 570 mm/yr. Minimum rainfall to build a RRWH-system of this type.
P ₃	Rainfall 1,200 mm/yr. Maximum rainfall found in Nakuru area (practically 6 m rain gutter units).
P ₄	Rainfall 1,460 mm/yr. Point C is the ideal for a 6 m rain gutter unit.
P ₂ -P ₃	Rainfall 570 - 1,200 mm/yr. Area of model applicability in Nakuru conditions
F ₂ -F ₃	Area of model applicability in Nakuru conditions
F ₁ -F ₃	Area of modification for rain gutter units and roof catchment area units and length of buildings.
Point B	Rainfall 570 mm/yr. Discovered by interpolation. It gives the optimum technical lower limit for the RRWH-system applicability. If the RRWH-system is build in drier areas, then the given RRWH/Co is changing. It is hinted, that under cost/benefit calculations the lower limit for the construction of this type of RRWH-systems might to be found in the range of 500 - 600 mm/yr. The calculation can, however, not be uniform because alone the value of water is so much area specific and highly variable.
*	One rain gutter unit comprises the rain gutter itself and one half drum.
Outcome	The area between the points (B,E,D,G and the section G-B in R-curve) is the area of model application in Nakuru area for a RRWH-system of this type.

Tree nursery design

The drip irrigation basin (DIB) was designed with the idea of two taps and with no water losses. (Figures 8 and 1). The upper tap, which is placed in the middle of the tank height is for general use as long as there is water above that level in the tank. All the water dropping from the tap or spilling when used is automatically harvested for the use of tree seedlings by the slanting DIB, which is made out of concrete. The lockable lower tap is reserved for the irrigation of seedlings in the dry spell. There is a lower bucket basin with an optional drainage, according to the general scarcity of water in a specific area. The overflow pipe of the water tank is discharging the excess water at DIB for additional seedlings irrigation and to protect the foundation of the water tank itself. In hot areas a shade over the DIB is needed to reduce the evapotranspiration of green plants. Protective fencing and locally available materials are key elements of a successful school nursery operation. The nursery area should be planted by different tree species for seed production and shade and to absorb logged rainwater.

COST-BENEFIT ESTIMATES

Underlying figures

In order to make cost-benefit estimates more comparable with other systems following facts are stated:

- MMM-project constructed a RRWH-system of this type in 72 primary schools.
- Annual water harvesting is 243,000 l/unit
- The cost of DIB and fencing of the school nursery area of 225 m² are included into the costs.

Summary of the cost of one RRWH-unit

A) MMM/Hardware materials including transport	KES	106,725
B) MMM/Building materials including transport		18,850
C) Community contribution including payment of artisans		24,630
D) Estimated annual maintenance		500
E) Other project overheads (training, tool sets, cars etc.)		17,398
Total		<u>KES 168,103</u>

Cost of water

The cost of water is calculated per m³. A capital recovery formula was used to count the uniform-series equivalent to a present sum. It involves the payments (recovery) on a sum of money (capital) placed in an annuity or some such fund. (Helweg, Otto J., 1985). The formula is

$$A = P \times \{i(1+i)^n\} / \{(1+i)^n - 1\}$$

The notation for the formula follows;

- A is a uniform annual series of payments
- P is the present sum of money
- i is the interest rate per period, normally per year.
- n is the number of interest periods (year).

By counting with 2 % interest rate:

i=2% ; capital recovery factor by n=30 years is 0.0447 (Szonyi, et al., 1984).

$$A = \text{KES } 168,103 \times 0.0947936 = \text{KES } 15,935$$

$$> \text{KES } 15,935 / 243 \text{ m}^3 = \text{KES } 66 / \text{m}^3 \text{ or } \text{USD } 0.94 / \text{m}^3$$

(USD = 70 KES, at the time of construction)

The comparable cost of water by 0% interest rate would be KES 23/m³ or USD 0.33/m³.

Assessing benefits

The benefits can be assessed by asking: "What can be achieved with an annual investment of USD 227 or 243,000 litre of potable water/yr over the next 30 years"?

1. Provision of 1 litre potable water for 500 people in 270 days/yr.
2. Production of 7,000 tree seedlings/yr for the school community.
3. Facilitation of tree nursery training and environmental education for 500 children/yr.
4. Facilitation of community school field days.
5. Water is used for cleaning purposes in school premises.
6. Formation of stagnant water pools in school compounds and near-by run-off areas is reduced, which could diminish the possibility of mosquito breeding.
7. Protection of the foundation of the school buildings through prevention of water logging, especially in areas of high clay content. Rain gutters are strengthening the roofing of school buildings against torrential rains and winds.
8. Training and work creation for 17 local artisans.

DISCUSSION AND CONCLUSIONS

An annual investment of USD 227/school or USD 0.45/pupil/school for the next 30 years can be justified in a community oriented forestry extension project. Availability of water is opening up new possibilities for the education of children in the fields of forestry, health and hygiene.

A forestry extension project can hardly utilize its resources better for an overall community development in order to meet the long term objective, which is to place the supply of essential tree products on a sustainable basis and of stabilizing and improving the rural environment through rural afforestation. The efforts are expected to be worth-while when used for training of young people, through whom a long lasting multiplier effect will be achieved. The input can potentially satisfy the demand of tree seedlings of the school community on a sustainable basis and accelerate an overall community development through products from trees as timber, fire wood or animal fodder. The investment is shared by many people over a long period.

The experience shows that it is technically possible and economically feasible to harvest the rainwater from the entire roofing area of large buildings at a RRWH/Co rate of > 80.

The example of MMM-project shows, that also the organisation of Forestry Extension Service Division can successfully be used in the development and construction of RRWH-systems.

A special merit is achieved through the protection of foundation and roofing of buildings and reduction of stagnant water pools suitable for mosquito breeding.

In this concept the problem of the first flush devise still remains to be solved, even if the half drums are provided with sieves and are occasionally self cleaning by heavy rains.

The possibilities of RRWH-technology should be included already in the planning stage of forestry and other community oriented (integrated) projects and adequate funding provided.

More information about the RRWH-development can be obtained from the Technical Report No 8. Improved Roof Rainwater Harvesting from Large Buildings, which describes the work in details and serves well as a manual.

References

- Helweg Otto J., Water Resources, Planning and management 1985. p.319.
Nakuru, District Development Plan, 1989-1993. Ministry of Planning and National Development.
National Atlas of Kenya, 1970. Drawn printed and published by Survey of Kenya.
Niemi, T., 1994. Technical Report No 8. Improved Roof Rainwater Harvesting from Large Buildings. Enso Forest Development Oy Ltd. Nakuru and Nyandarua Intensified Forestry Extension Project
Pehu, E. & Smith Saulniers, S. 1991. Technical Report No 1. Socio-Economic Baseline Survey. Enso Forest Development Oy Ltd. Widagri Consultants Ltd. Nakuru and Nyandarua Intensified Forestry Extension Project.
Project Document, 1990. Nakuru and Nyandarua Intensified Forestry Extension Project
Szonyi, et al., Principles of Engineering Economic Analysis (Canadian Edition) (New York: John Wiley, 1984).
WHO (1984). Guidelines for Drinking-water Quality, Vol.1, Recommendations. World Health Organization, Geneva, Switzerland, pp.1-130.

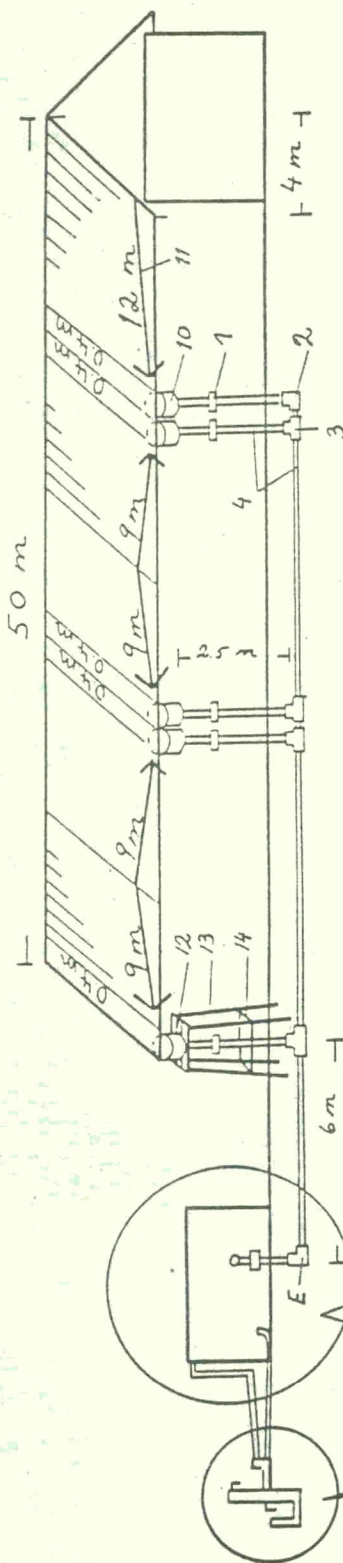
Table 1. Summary of Rainfall & Inflow & Demand & Overflow & Balance
Example of Pangani Primary School's RRWH-system/Municipality Division/Nakuru District/ Kenya

Month	RAINFALL		INFLOW		DEMAND		OVERFLOW		BALANCE	
	Average Rainfall (mm) *	RRWH/Co ₂	Monthly Volume (m ³)	Cumulative Volume (m ³)	Nursery Irrigat. (m ³)+	Drinking Water (m ³)**	Cumulative Volume (m ³)	Water from Tank (m ³)	Water in Tank (m ³ ***	
April	130	75	34	34	7	Holiday	7	0	27 (Full)	
May	130	75	34	68	7	11	25	16	27	
June	80	80	22	90	7	11	43	4	27	
July	100	75	26	116	7	11	61	8	27	
Aug	100	75	26	142	7	Holiday	68	19	27	
Sep	64	80	18	160	7	11	86	0	27	
Oct	61	85	18	178	8	11	105	0	26	
Nov	63	85	19	197	8	11	124	0	26	
Dec	40	90	12	209	8	Holiday	132	3	27	///
Jan	20	95	7	216	8	11	151	0	15	///
Feb	32	90	10	226	8	11	170	0	6	///
Mar	55	90	17	243	8	11	189	0	4	///
Total	862	83	243	243	90	99	189	50 ****	4	#

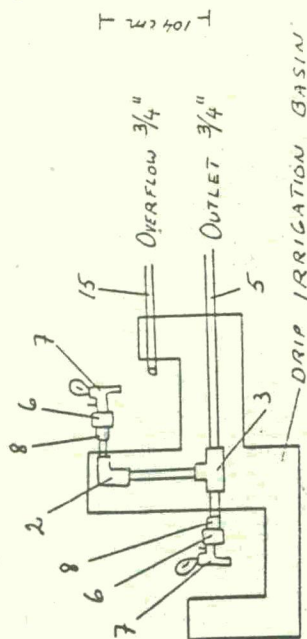
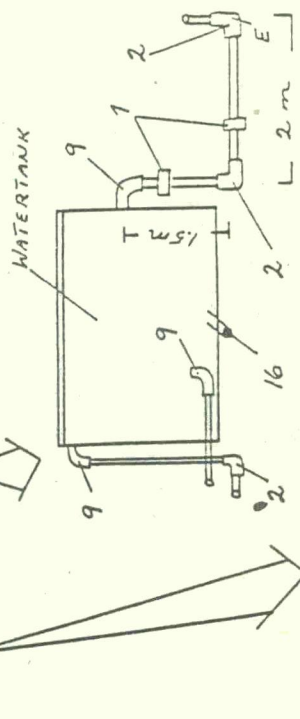
Notes:

- 1 The Pangani Primary School's RRWH-system collects water from a 50 m long x 8 m wide building with two lines of piping (1" and 1 1/4") one for each side of the guttering/half drum units. (Figure 1). The capacity of the RRWH-system is 27 m³. The roof catchment area on both sides of the building is divided in 5 using 3.5 m effective width for one roofing side. Instead of the RRWH-system, the water could be collected in a tank, done according to the output of 1 1/4" piping system and by RRWH/Co₂ - Roof Rainwater Harvesting Coefficient of 1 1/4" piping system.
- 2 Example is counted for Nakuru town/Municipality division. Average rainfall of 56 years (862 mm/yr). (Atlas of Kenya, 1970).
- 3 Counting is based on 22 school days/month and 3 months for holidays in a school year. Water demand is 1 litre water for drinking and washing hands for 500 people. The effective water holding capacity of the tank (412 cm inside diameter x 200 cm height) is 27 m³. Volume of the central pillar is discounted.
- 4 The calculated overflow is a technical term for the flow of water through the RRWH-system. In practical terms the overflow is not water which is wasted, since it is under Headmaster's control. For example; school children can be allowed to take water to their homes in times the tank is expected to overflow or water from the full tank can be used for washing or to bind dust in classrooms. The overflow is to be understood as Headmaster's reserve. It is the contingency of the system, which can be directed according to the school community's preferences.
- 5 Level of irrigation: dry period (0.15 1/day x 25 days/month x 2,000 seedlings) and wet period (0.1 1/day x 15 days/month x 5,000 seedlings).
- 6 December, January, February and March are critical months regarding the availability of water. The down outlet tap (Figure 1/Code 7) is always of a lockable type and under Headmaster's control.
- 7 The water balance after the first year's operation is 4 m³, which is to be counted as an overflow from the tank for the next April. During the first year's operation the tank became filled 5 times, which means that the turnover of the water was about 5 weeks.

RWH-SYSTEM, PIPING & GUTTERING, GENERAL SIDE VIEW FIGURE 1.

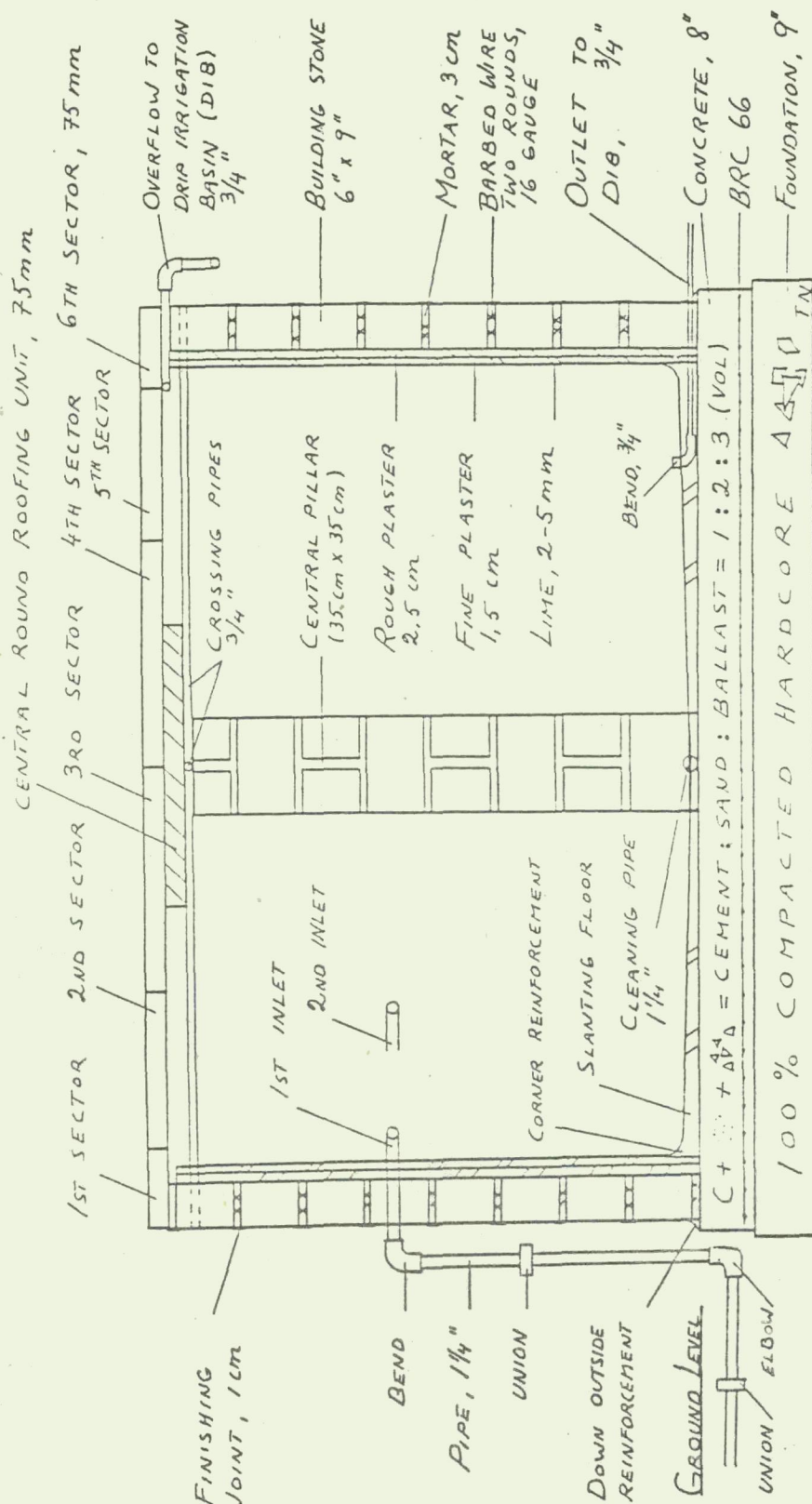


MATERIALS, PIPING & GUTTERING (ONE SIDE)				DETAILS	CODE
PIPES					
HORIZONTAL	46 m	10 PIPES, 1 1/4"		6-2	4
VERTICAL	14 "			6-3	5
OUTLET	8 "	3 PIPES, 3/4"		6-3	13
OVERFLOW	10 "				
CONNECTIONS					
UNION	1 1/4"	1"	3/4"	1 1/4" x 3/4"	1
ELBOW	3				6-1
T-JOINT	4				6-1
SOCKET *					6-1
LOCKABLE TAP		2			6-5
REDUCTION				2	6-5
BEND	1		1+1		6-3
CAP, CLEANING PIPE	1				6-4
RAIN GUTTERS					
GCL-SHEETS, 28 GAUGE	3 m, 10 PCS, INCL STRIPS			6-8	11
HALF DRUMS					
5 PCS, 1 1/4" SOCKET AND SIEVE				6-11	10
DRUM STANDS					
TIMBER { 2" x 3" } x 3				6-9	14
" { 6" x 1" } x 3					12
POSTS, RED BLUEGUM OR CEDAR, 10 FT x 12 PCS					13
* EVERY PIPE IS DELIVERED WITH ONE SOCKET					T.M.



WATERTANK, CROSS SECTION

FIGURE 2.



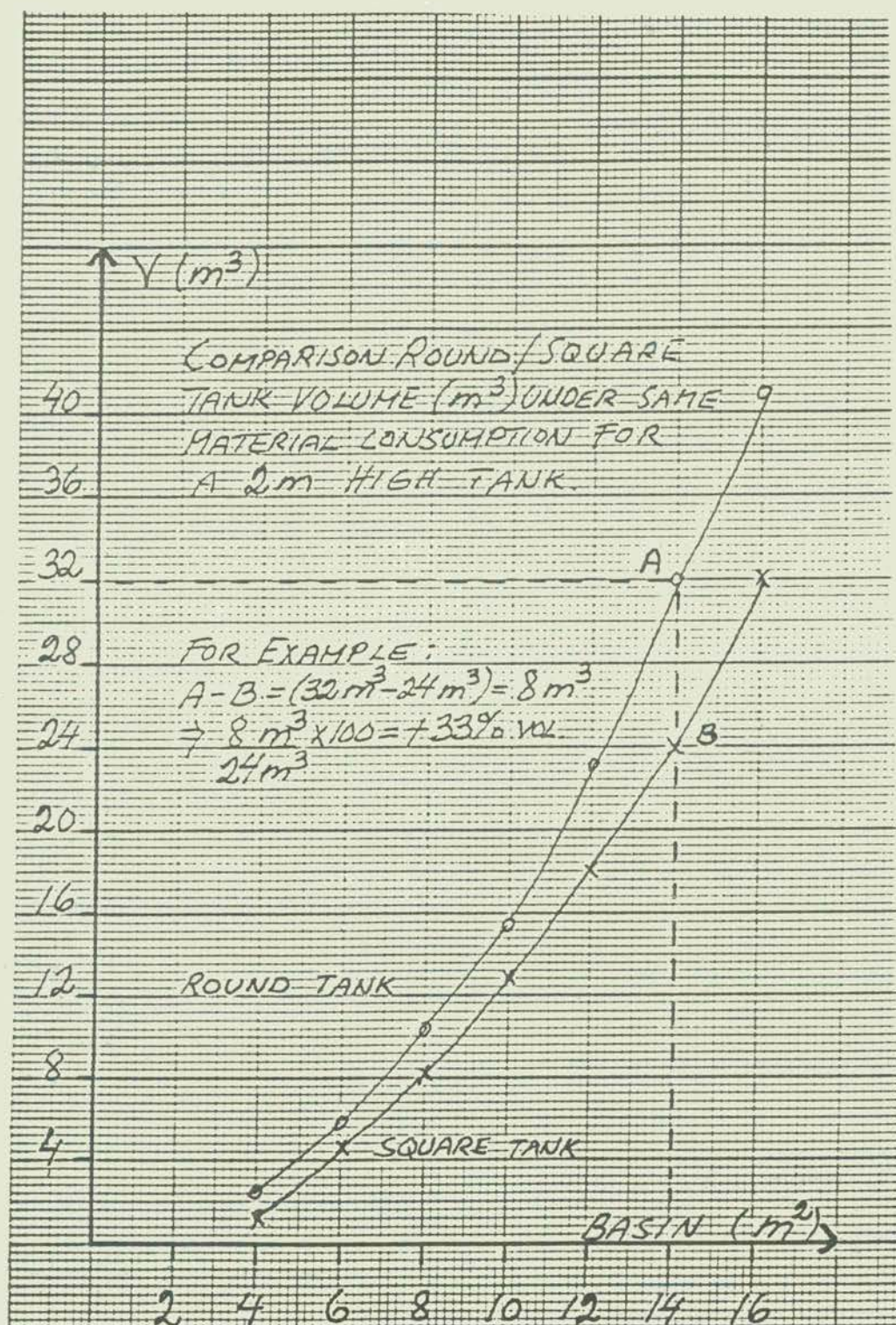
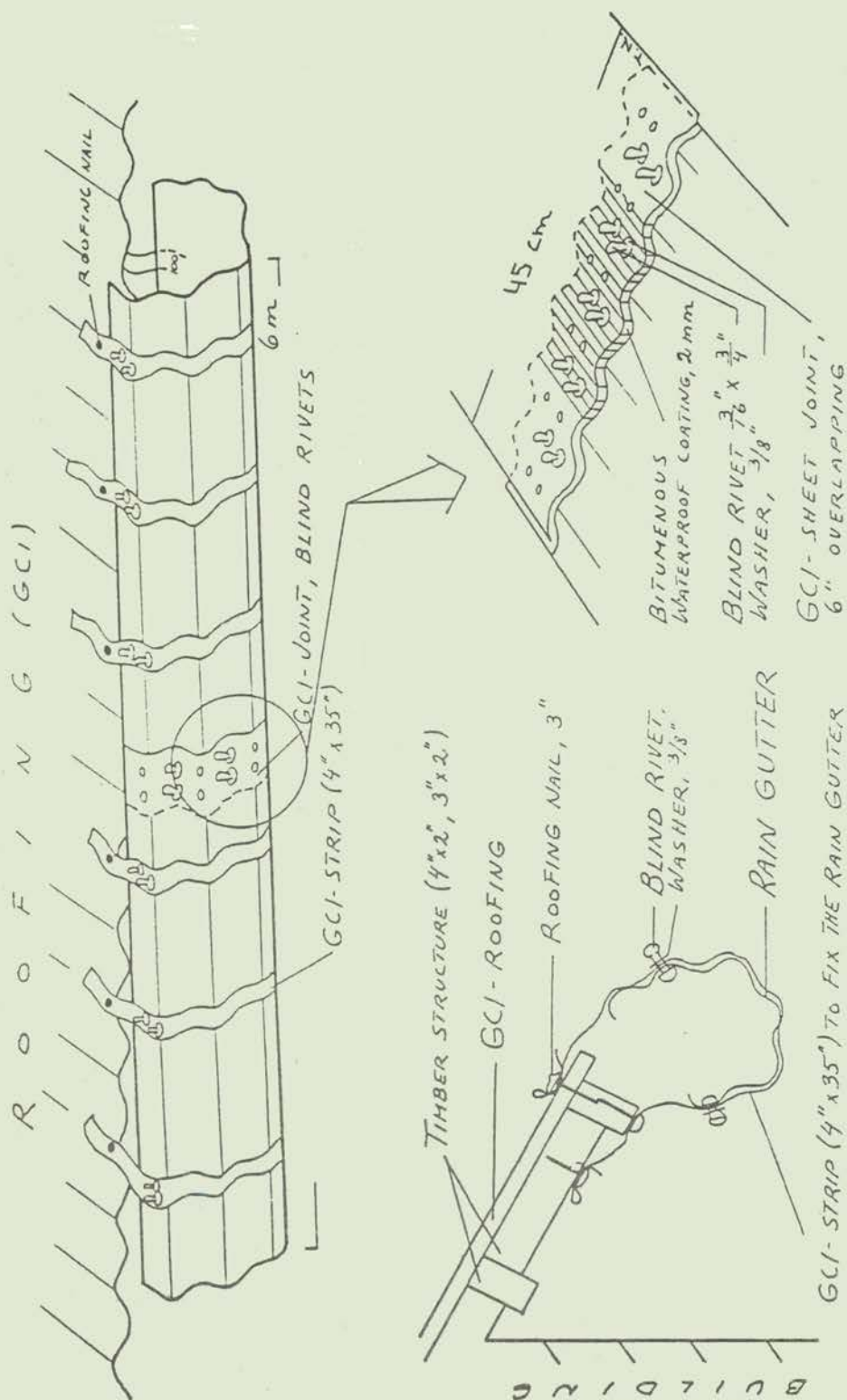


FIGURE 3

RAIN GUTTER, DETAILS

FIGURE 4.



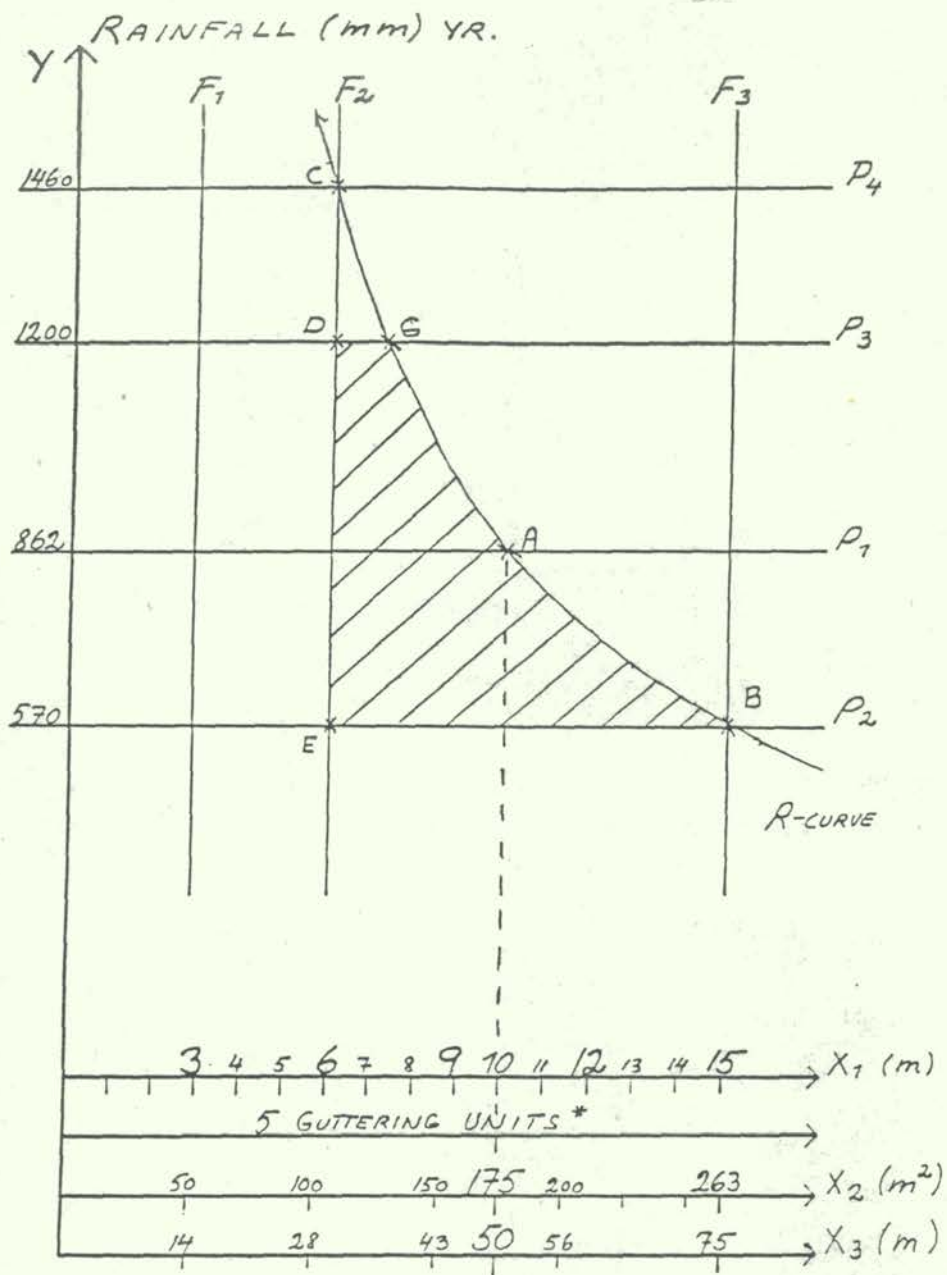


FIGURE 5

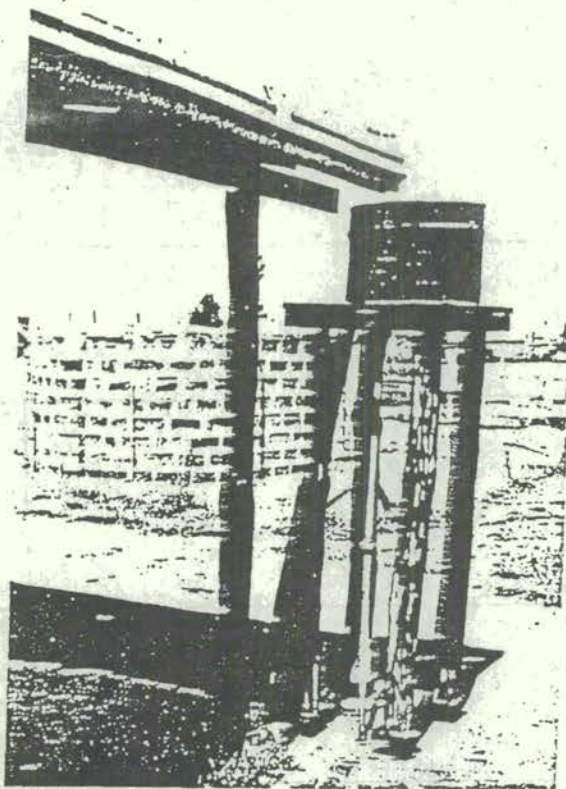


Figure 6. Water harvesting by GCI-rain gutters, half drums, galvanized pipes and storage by a water tank made out of natural building stones with a concrete slab roof.

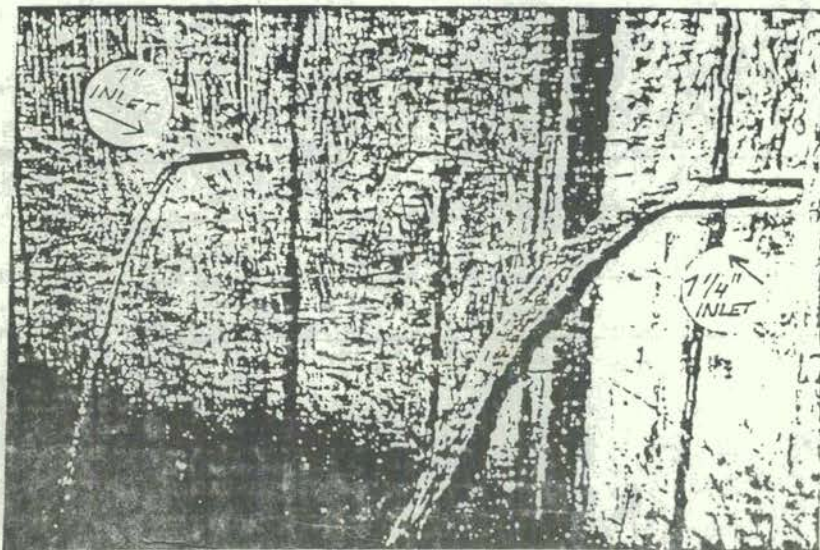
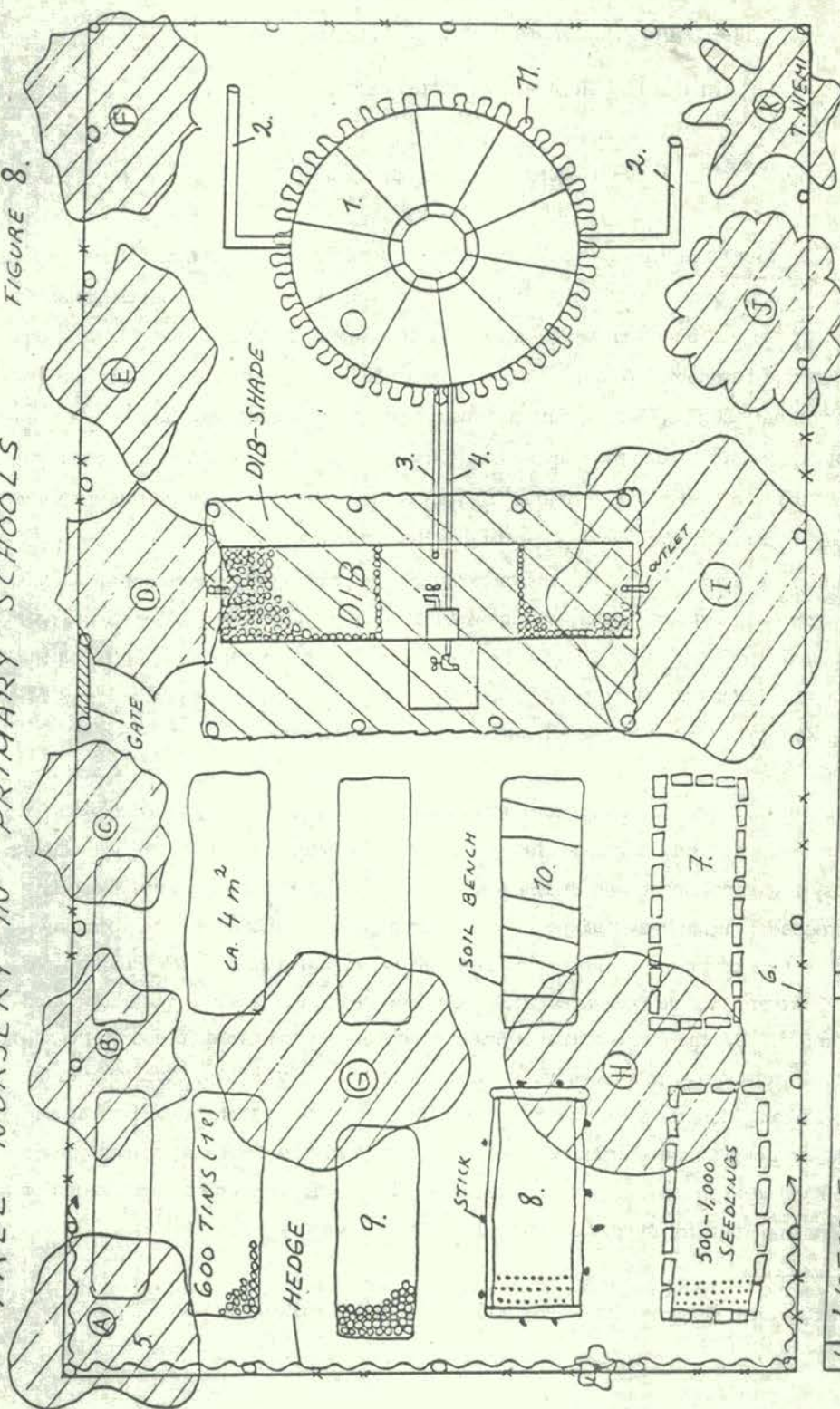


Figure 7. Comparison between 1" and 1 1/4" pipelines, which are both conveying water from a similar 175 m² effective catchment area. Maximum output of the 1 1/4" line is 70 l water/min.

TREE NURSERY IN PRIMARY SCHOOLS

FIGURE 8.



1	WATER TANK	5	①-③ TREE SPA. AS SEED SOURCE AND SHADE	9	AREA FOR SEEDLINGS (TINS)
2	WATER INLET LINE	6	*** BARGED WIRE AND POST	10	SEED BED
3	OVERFLOW	7	SWAZILAND BED FROM LOOSE STONES	11	FLOWERS AROUND THE TANK
4	OUTLET	8	SWAZILAND BED - TIMBER - LOGS - BANANA etc.	12	NURSERY AREA CA (12m x 20m)

The Utilization of Rain Water Harvesting System in the Development of Courtyard Economy

Wanjuan Zhang *, Yonghui Yang *

ABSTRACT: Rain water harvesting system has been used for several thousand years in China. But till now, its techniques still stay in the original level. On the basis of investigation on styles of courtyard, we found that water harvested from courtyard could be used for the development of courtyard economy. And by means of practical analysis, it was showed that water collected from rain harvesting system in courtyard could recover investment very quickly. And the development of courtyard economy could stimulate the extension of water harvesting systems.

So, this system can be used not only in areas with serious problems in getting drinking water but also areas where courtyard economy can be developed through rain water harvesting.

In addition, a typical area in Taihang mountain, the principle for the design of water harvesting system was put forward. It was showed that the minimum size of water saving pool can be calculated from the following equation: $V = W_{y,m} - W_{y,n}$. It lays a foundation for the development of rain water harvesting in Taihang Mountain.

Key Words: Rain water harvesting, roof catchment, courtyard economy.

Courtyard is one important center for human activities. It is also a margin of ecological research. There are many advantages in this system, rich in natural resources, enough labor force and easy for management, which as a whole make it a high effective system. Nowadays courtyard production has already become one of the three major productions in rural economy. The development of courtyard economy has made many peasant a better life. Products produced from courtyard include vegetables, fruit, Chinese medicine, flowers, mushroom, and products of animal. But the fact is that all kinds of production in courtyard depend on the supply of water. Unfortunately, in a lot of areas, water resources is very limited. According to the statistics, in Taihang Mountains, in a year with average precipitation, there are 436 villages in which people can not get enough drinking water. And in a year with lower than average precipitation, 1750 villages can not get enough drinking water. So the collection and utilization of rainfall is very important for the development of courtyard economy.

* Assistant Research Professors, Agroecological Dep., Institute of Agricultural Modernization, CAS, Shijiazhuang, 050021.

The utilization of rainfall has a very long history in China such as the use of wells below ground for water saving and karez in northwest part of the country, the use of man-made well for collection of rain water in north China. But up to now, little has been done on the research of rain water harvesting.

The major purpose of this paper is to show the potential of rain water harvesting in Taihang Mountain.

I. The relationship between the styles of Chinese courtyard and rain water harvesting

The way of rain water harvesting is strongly related to the styles of the courtyard. China is a big country with 56 nationalities. Every nationality has its own courtyard style. In the northern part, people lived in a compound with houses around a courtyard. In the southern part, some people lived in the attic. In Sichuan province, people construct house in the middle of the land and so on. To some extent, the styles of the house has a good relation to local climate such as temperature, rainfall, wind speed etc. For example, in southern part where there is a plenty of rainfall and in northeast areas where there is a lot of snow in the winter, roof usually was designed as triangle to drain off water. In northern part the flat roof is due to the low rainfall. The triangle roof usually are covered with straw or tile, meanwhile, the flat one covered with soil or concrete. Different roof styles will use different way to collect rainfall. And the materials used for the construction of the roof will affect the quality of water collected. Nowadays, people usually cover roof with tiles or concrete. Those are good materials for the harvesting of rainwater in the courtyard.

The size of courtyard in different areas is variable. It mainly depends on the area of land that one person owns. It ranges from 0.2 to 2.0 mu. For instance, in northeast China, and in the inner Mongolia, the size is usually about 1 to 2.0 mu, but usually only about 0.1 to 0.3 mu in the southeast part, and about 0.5 mu in northern China. If the courtyard is large and the area for house is relatively small, the harvesting of rain water will greatly depend on the courtyard. Other wise, like in the north and in the southeast, roof will be important for rain collection.

The area where the analysis was done is in Taihang mountains, which locates in northern China. It is a semi-arid area with annual precipitation 500 to 600 mm. In this area, the construction style is usually a compound of houses in three direction around the courtyard. Roof is usually made of concrete. Average size for the whole courtyard is about 0.4 mu in which house take about 0.3 mu. So the harvesting of rain water will mainly depends on the roof. In addition, rainfall mainly induced by continental monsoon climate. In the period from June to August, rainfall accounts for about 60% of precipitation in the whole year. So the saving of rain

water becomes a main problem.

II . The design and construction of roof for rain water harvesting .

The roof water harvesting system is mainly composed of four parts: roof catchment, the pipe for rain water collection , filter pool, and water saving pool.

1. Roof catchment:

Because roof in this area is made of concrete, there is no need to spend a lot of money on changing of roof materials. The ideal roof for this purpose should be hard and flat. Some experiments showed that if the verage runoff parameter is 0.7 in the dry season, then in the rain sea son it is about 0.8. And the water quality is almost as good as it was before it dropped to the ground. And it is better than the water people are drinking. The only thing need to be done is to construct a 5 to 10 cm high dam in the edge of the roof to hold water. Meanwhile, keep some outlets in the dam.

2. The collection of water:

It comprises of pipes for draining off water and pipes for water collection. The pipes for draining off water are pipes coming from outlets in the dam. And it connect the major pipe for water collection. Usually pipe 2 inch in diameter can be used. Water collection pipe connect all pipes for draining off water. Pipe of 3 inch in diameter will be useful. A little angle should be kept to let water drain off smoothly. It can be designed above the ground or near the roof. On the end, it connects the filter pool.

3. Filter pool:

It can be a pool 60cm in length, 30cm in breadth and 60cm in depth. It usually is made of concrete. In the middle of the pool, there is a board made of concrete, to hold water go directly from the inlet to outlet. Inside the pool, stone, sand are put into in different layers to hold back some straw or other materials. In another side, filter pool connect the water saving pool.

4. Water saving pool.

It is the most important construction in this system. There should be inlets, outlets, and mouth for lifting water, and cover. It can be constructed above or below ground. If in winter temperature drops below 0°C, it would be better to construct the pool under ground or half way below ground to avoid frozing. If it is constructed below ground, the mouth of the pool should be kept higher than the ground level to provent some materials from going inside. Many materi als can be used for construction. But the common material is concrete. This part is also the most expensive part in the whole system. In order to decrease investment, while do not low down the amount of water for saving, the smaller the poll is desighed the cheaper it is. So the design of the pool size is the most important point.

The design of the size of water saving pool:

The design of the size of water saving pool always depends on the annual precipitation, the size of roof catchment, and the amount of water to meet peoples' need.

In general, if an area is controlled by monsoon climate with apparent dry season and rain season, the size of the pool should be bigger. On the other hand if rainfall is well distributed, the size can be smaller.

In Taihang mountain, the climate is mainly controlled by monsoon climate with a long dry season. The size of the pool should be big enough to meet the need of water in the dry season. The design should minimize the size of the pool meanwhile do not waste rain water. So it is necessary to calculate the minimum water need in each family.

If the amount of rain water collected is higher than family's need, the size of the pool should be designed on the basis of minimum water need. In this case, it can be calculated from equation (1). On the other hand, if the amount of rain water lower than family's need. It is better to save as much water as possible. The work can be done through equation (2).

$$(1) V = W_{h,x} - W_{h,j} \quad (2) V = W_{p,j} - W_{p,x}$$

Where: V —the minimum size for the pool (m^3)

$W_{h,x}$ —the minimum water need in the dry season. (m^3)

$W_{h,j}$ —the amount of water can be collected in dry season (m^3)

$W_{p,j}$ —the amount of water can be collected in rain season (m^3)

$W_{p,x}$ —the amount of water needed in rain season (m^3)

In addition, two variables need knowing. The first one is W_x which is the minimum water need. Another one is W_j , which is the amount of water can be collected. W_j depends on precipitation, runoff coefficient and catchment area. It can be calculated from the following equation:

$$W_j = m \cdot r \cdot s,$$

Where: m is precipitation in mm.

r is runoff coefficient.

s is the catchment area in m^2 .

Variable m is the factor which most difficult to sort out. Because it is difficult to predict the amount of precipitation in a year. And it changes a lot in different year. In general, we could get different season's rainfall by monthly average precipitation. Variable r can also be obtained through many years' investigation. That means, in a certain region, precipitation and runoff coefficient are constant. The only variable is the size of catchment. And the size of catchment is the only factor influencing the size of water saving pool in different family. Following is an example which show how a water saving pool was designed in Yuanshi County, one county in Taihang mountain.

According to the investigation, the minimum water need in a family with 4 to 6 people is 40 to 60 kg per day. 20 kg/d is needed for each draught animal. And 10kg/d for pig and sheep. Averagely a family need about 110kg/d of water. The development of courtyard production such as fruit tree, medicinal plants, flowers etc. need 4 ton of water per season. In addition, this investigation was held in winter when the amount of water needed was lower. In spring, it could increase about 20% and summer 50%. So the amount of water for one average family is about 52 ton/year.

During the period from Nov. to May, this area is in dry season. The rain season is in the period from June to October. Table 1 shows the distribution of precipitation in an average year. The investigation showed that in dry season, runoff coefficient times precipitation is 23.8 mm, then $W_{n.s.} = 0.0238 \cdot s$. And in rain season runoff coefficient times precipitation is 274.7mm, then $W_{y.s.} = 0.2747 \cdot s$.

Table 1. The roof runoff in different month in Taihang Mountain

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
Monthly precipitation (mm)	0.1	7.1	8.9	17.5	21.5	16.2	135.7	111.8	52.4	28.0	13.0	4.5	514.0
Monthly runoff coefficient		0.22	0.20	0.37	0.42	0.49	0.80	0.78	0.76	0.62	0.43		
Monthly precipitation times runoff coefficient (mm)	0	1.68	1.81	6.38	9.56	22.73	108.62	87.10	40.58	17.30	1.33		298.48
Monthly precipitation times runoff coefficient in different season		19.37					274.73					4.38	

To meet the need of 54 ton of water in one family, yearly collection of water should be $54 = 0.2985 \times s$, then $s = \frac{54}{0.2985} = 180m^2$. So if the size of catchment is larger than $180m^2$, the size of water saving pool can be calculated from equation 1. Otherwise equation 2 should be used. According to our investigation, the average size of roof catchment in each family is about $150 m^2$. So in this region, it is better to used equation 2 for calculation.

The minimum size of water saving pool is:

$$V = W_{y.s.} - W_{n.s.} = 0.2747 \times 150 - 24.75 = 16.46(m^3)$$

III. The development of courtyard economy and the rain water harvesting

1. the harvesting of rain water will stimulate the development of courtyard economy.

The productions of courtyard economy mainly include vegetables, fruit trees, medicinal plants, mushroom, and animals. No matter which kind of production, water is necessary. Ac

cording to our investigation, aside from the natural rainfall, the production in each 100 m² of land need 8 to 10 m³ of water for vegetable, 4 to 6 m³ for fruit tree, and 10 to 100 m³ for mushroom. In general, productions in courtyard are intensive, 6 m³ more water is needed in every 100 m² of courtyard. In fact, without convenient supply of water, it is not possible for the development of courtyard economy.

2. The development of courtyard economy need the support of rain water harvesting system.

Courtyard economy is one of the three main kinds of productions in rural economy. For example, the products of vegetable in every 100 m² of courtyard can bring 800 to 900 yuan to the farmer, fruit 600 to 800 yuan, mushroom 1000 to 1200 yuan. That is a big income for most farmers. Supposed the techniques of rain water harvesting are used in the development of courtyard economy, the investment for the construction of the water saving pool can be easily taken back. It is a better way to stimulate the development of water harvesting system. In addition, the development of courtyard economy depending on the water harvesting system will break through the concept that water harvesting system can only be used in areas where drinking water is very limited, and areas where drinking water is enough can also use this system to develop courtyard economy.

3. The relationship between production in courtyard and drinking water.

Since the development of courtyard needs a lot of water, the size of the water saving pool should be bigger. The investment of the water saving pool will be higher. But the water need most for the production is in the rain season. According to the principle, the size of the water saving pool mainly affected by the amount of precipitation in the dry season. So it will not cause a big problem. In fact, water saved in the pool mainly are prepared for the use of human and animals in the dry season. The use of water for courtyard production is limited. It should not conflict with drinking water.

In addition, in some areas, with a big courtyard, a huge water saving pool can be constructed for the collection of rain water.

In the areas where there is no problem in drinking water for human and animals, the collection of rain water will only be used for the development of courtyard economy. The design for the water saving pool is easier. Water quality will not be considered as the main factor for the selection of construction materials. The investment will be much lower.

IV. The potential and prospect of water saving system in courtyard.

The harvesting of rain water in courtyard is a economical and effective way to use water. There are many advantages in this system such as low cost, high effective, and long-term benefit. It can bring us not only environmental and ecological benefits but also economical benefit. It is sure that it will be broadly used in next century. In China, there is a lot areas with serious water shortage problem even for drinking water, and a lot of areas where the drinking water is

too salty to meet the international standard. So the development of rain water harvesting system will have a great future. The development of courtyard economy depending on the collection of rain water in the courtyard and roof can greatly stimulate the development of this system. We believe, once people and the government get to know advantages, this system will play a very important role in the development of rural economy in poor and dry areas.

Reference

- [1] J. E. Gould (1992), Rain water harvesting, IRCSA, Japan Toyko.
- [2] L'vovitch M. I. (1975), World Water balance, selected work in water resources, Asit K. Biswsa(ed), IWRA.
- [3] Changming Liu (1993), Water resources and its utilization in agricultural ecology, Research on Agricultural Ecology, Vol 3. ,PP20—26.
- [4] Haisheng Mou(1993), The development of water resource utilization, Research on hydrology, Vol 4, PP57—60.
- [5] Fog water for arid area, Canada's International development research centre, 1992.

WATER CELLAR ---- SAFE, CONVENIENT AND COST-EFFECTIVE

Zhang Chaoyang Ge Maohang Song Wei Wang Yongsheng*

WATER RESOURCES DEPARTMENT OF HEBEI PROVINCE

North China Institute of Water Conservancy and Hydro-Power

ABSTRACT

Based on the conventional bottle-like water cellars, water cellar engineering for drinking water has been developed by Water Resources Department of Hebei Province. It has thoroughly overcome the drawbacks of the conventional water cellars, such as bad hygienical conditions and the tendency for water to become putrid. The experiences have shown that both water capacity of and water quality in the new cellar can meet the need of the users living in the areas where freshwater is rare provided the cellar is well designed and constructed. The results of water analyses indicate that the total number of bacteria in the new cellar is less than 80 per ml which is conformed to the Drinking Water Sanitary Standard of People's Republic of China. The article presents the information of the new water cellar engineering for drinking water. Up to now, more than 1,500 water cellars scattered in 30 counties in Hebei Province have been built up. Because the new cellars are safe, convenient, and cost-effective, they are widely welcome by people who live in the mountain areas where freshwater lacks.

Key words: rainwater cistern runoff surface

Background

In mountain areas where freshwater is rare, water cellars have been used to catch and store rainwater for the principal freshwater supply for generations. The conventional cellars used in China were shaped like bottles. The rainwater ran off the house tops to courtyards, where it was directly collected and stored in cisterns. However, during the collection of stormwater, silt and excrement more often than not entered the cisterns along with the rainwater. Due to the long detention time of the water in cisterns, the water gradually became disgusting. In this quiescence water, microorganisms (even some observable creatures) reproduced themselves quickly, so that turbidity, taste and odour occurred, and it is easy to cause epidemic disease. The people would rather fetch water from places several Kilometers away than utilize the conventional water cellars.

In 1984, a decision was made by Water Resources Department of Hebei Province to allocate special funds for technological innovation of the conventional water cellars. The project was called as water cellar engineering for drinking water. As the result, under the guide of experts, more than 500 mountain villages scattered in Hebei Province have set up now water cellars up to now. In the water cellar engineering for drinking water, the processes of sedimentation and filtration are employed, and the configurations of cisterns are changed and no long in the shape of bottles. Water quality in the new cellars is excellent. It has been shown that the collection of stormwater is a low cost technology to solve the potable water problem in mountain areas where freshwater lacks. As compared with other procedures of water treatment, it has some obvious superiorities. The article is to sum up the practical information related to the water cellar engineering for drinking water.

Water Cellar Engineering for Drinking Water

Flow scheme of water cellar engineering for drinking water developed in Hebei is illustrated in Fig.1.

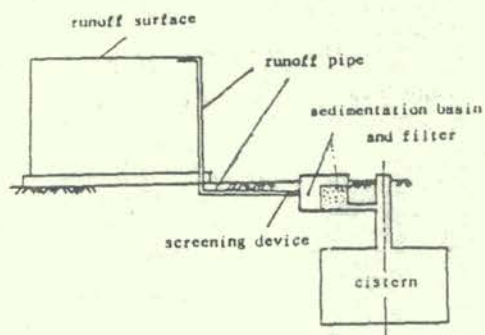


Fig.1. Flow scheme of water cellar engineering for drinking water

The rainwater runs off the house tops to the troughs, where it is collected in runoff pipes, and then clarified while running through screening devices, sedimentation basins and filters into cisterns. The water cellar engineering for drinking water may consist of five general parts: runoff surface, collection channel and runoff pipe, screening device, sedimentation basin and filter, and cistern.

1. Runoff Surface

Runoff surface is one where rainwater is collected as precipitation occurs. House tops and courtyards are usually used as runoff surfaces. Generally speaking, the required area of runoff surface is directly related to precipitation pattern, and thus to meteorologic, geographic, topographic, geologic condition; and the required amount of water, and thus to the required volume of water cellar. Mathematically, this may be stated as

$$F = \frac{1000V}{KH} \quad (1)$$

where F = the required area of runoff surface (m^2)

V = the required volume of water cellar (m^3)

H = the average annual rainfall (mm)

K = runoff coefficient

Respectively, the average annual rainfall and the average runoff

coefficient in mountain areas off Hebei Province are 500 mm and 0.7.

Utilizing the equation 1, the required area of runoff surface can be determined for the required volume of a water cellar is $V = 35 \text{ m}^3$ (see latter), then

$$F = \frac{1000 \times 35}{0.7 \times 500} = 100 (\text{m}^2)$$

In mountain areas of Hebei Province, a family often has four houses (Fig.2.), and their tops have a total area of runoff surface of about 80 m^2 . In order to meet the need of water of 35 m^3 , another man-made area of 20 m^2 must be established in courtyard.

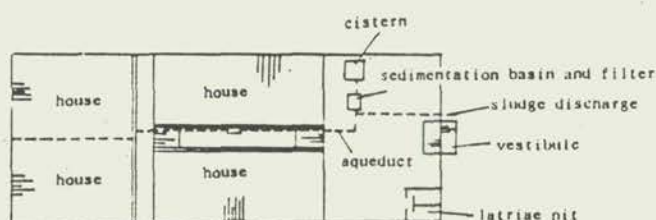


Fig.2. Runoff surface of a family with four houses and a courtyard.

2. Collection Channel and Runoff Pipe

Rainwater from runoff surface is collected in troughs, and then through aqueducts, transported to the sedimentation basins and filters, then into cisterns. Both troughs and aqueducts may be formed of brick, stone, synthetic rubber, iron sheet, plastic, or pottery clay.

The troughs which are in the form of rectangular or semicircle can be fixed under the eaves by means of reinforcing (Fig.3.). In some cases, collection channels can be built in the ground.

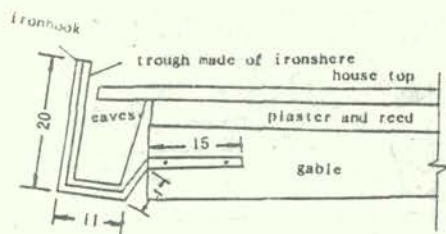


Fig.3. A trough fixed under the eaves by means of reinforcing

3. Screening Device

Rainwater frequently contains large suspended floating debris varying in size from logs to small rags. These solids can log filter or impede the hydraulic flow in the runoff pipes. Screening devices which are usually set in rainwater channel inclined $30-45^\circ$ with horizontal is the first step to treating water containing large solids. They are constructed of wood or steel bars with clear openings from 10 to 20 mm.

4. Sedimentation Basin and Filter

Sedimentation basins are used to remove both inorganic and organic materials which are settleable or which have been converted to settleable solids. Filters are used to remove nonsettleable impurities remaining after sedimentation of the water. Both sedimentation basins and filters are constructed of brick and stone, and their insides are coated with mortar to seal them. Fig.4. shows the sedimentation basin and filter used in water cellar engineering for drinking water.

It is advisable that a filter is divided into three shelves. The first is fitted with coarse sand or gravel with diameter from 1-8 mm. The second gravel with diameter from 8-17 mm, the third cobble with diameter from 15-20 mm.

Sludge discharge holes should be set up at the bottoms of sedimentation basins and filters to remove wastewater and sludge from them.

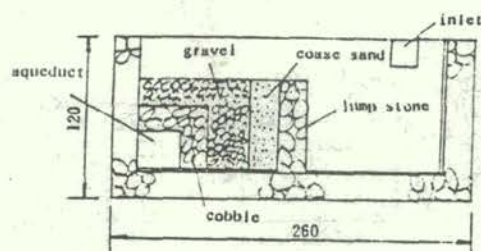


Fig.4. Sedimentation basin and filter used in water cellar engineering for drinking water

5. Cisterns

The cistern is a place where the rainwater is stored. The required volume of a cistern is directly related to residential water consumption, and the spell of drought. This may be stated as follows:

$$V = \frac{nTB}{1000}$$

②

where V = the required volume of cistern (m^3)

n = the maximum per capita consumption (L/p.d)

B = the total number of men or domestic animals (p)

T = the average days of drought (d)

Table 1 represents the water requirement of men and domestic animals in Hebei Province.

Table 1. the water requirement of men and domestic animals

man	cattle or horse	pig or sheep
15	30	10

Unit: L/per capita.day

In Hebei Province, where the average spell of drought in a year is about 5 months. There are averagely four men in a family which raises a head of cattle or horse, and a head of pig or sheep. Then the required volume of a cistern is

$$V = \frac{15 \times 5 \times 30 \times 4}{1000} + \frac{30 \times 5 \times 30 \times 1}{1000} + \frac{10 \times 5 \times 30 \times 1}{1000}$$

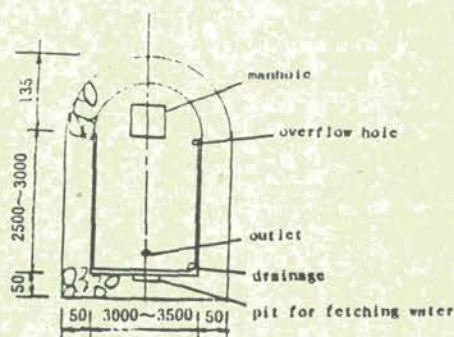
$$= 15 \text{ (m}^3\text{)}$$

In order to meet the need for two years, the required volume should be 30-35 m³, which complies well with the related regulations by the State of Council of People's Republic of China.

Quite different from the bottle-like cellars, the newly developed cellars formed of brick and stone, and covered with an arch to keep the water cool and free of impurity is in the rectangular shape (Fig. 5.). As compared with the conventional ones, they have the following advantages:

- ① Long service life, low storage losses and the cellars' tops available for farming.
- ② Large water capacity (30-40 m³) which is three or four times that of the conventional ones.
- ③ Excellent water quality.

Water quality analyses has been made in some places. The results indicates that the total number of bacteria is less than 80 per ml which is conformed to the Drinking Water Sanitary Standard of People's Republic of China in which the total number of bacteria is equal or less than 100 per ml.



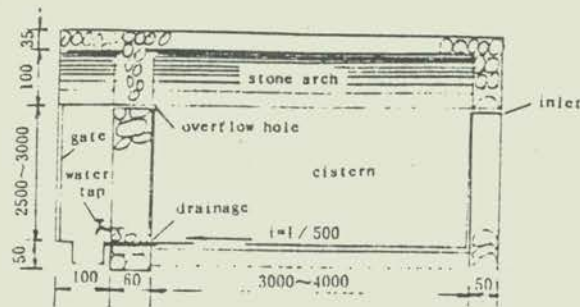


Fig.5. The configuration of the newly developed cellar

The location of a cistern must be carefully selected because it has an obvious bearing on the water quality. The location must be far away from latrine pits, composts, houses and big trees, the distance to them must be greater than 2-3 m. There are two choices for locating a cistern. One choice is to build it in the courtyard. Another is to build it on the upland behind the house, in this way, a water tap can be installed.

Summary

Based on the conventional water cellars, water cellar engineering for drinking water has been developed. It overcomes the drawbacks of the bottle-like cellars, such as bad hygienical conditions, and the tendency for water to become putrid. The practical experiences in Hebei Province has shown that both water capacity and water quality in the new cellars can meet the need of the users in the mountain areas provided the cellars are well designed and constructed. Up to now, more than 15,000 water cellars scattered in 30 counties have been built up in Hebei Province, and thus the number of people profited from them comes to more than 70,000. Water cellar engineering for drinking water is widely welcome by people who live in the mountain areas where freshwater lacks because it is safe, convenient and cost-effective.

RAINWATER HARVESTING FOR
BUONAVISTA GALLE - SRI LANKA
BY
THE CHURCH OF CEYLON BOARD OF WOMEN'S WORK
AND
THE ARCHDEACON OF GALLE.
Mrs. Jessica Alles

LACK OF WATER IS A PROBLEM and women as principal users of water in the home are more affected than men. This paper describes the circumstances which led to the course taken by our organization to try Rainwater Harvesting when all other sources failed to provide sufficient water for the Church and the poor community living around our Church in BuonaVista. The technique used is innovative as rainwater collected from roof cover is not practised in Sri Lanka.

INTRODUCTION :

The Church of Ceylon Board of Women's Work is comprised of representatives nominated by our Bishops and Committees within the Anglican Church in Sri Lanka such as the Mothers' Union, the Youth Movement, Social Responsibilities etc. In April this year we hope to celebrate 50 years of Service to the Church and Nation. Limited funds are made available to us for administration and we always have to seek funds from funding agencies for our needs for Community Service. Although our membership is small, we can network through our members and Churches Islandwide. We are happy to mention that when we need help, the members of our Church who are highly qualified offer their expertise willingly and free to us.

PROJECTS UNDERTAKEN CURRENTLY ARE:

1. Maintaining an Elders' Home for widows of Clergy and retired women Church workers.
2. Training Rural and Plantation Women in income-generating skills in Sewing, Lace-making, Home Gaedening, Beekeeping etc.
3. Organising Nutrition Programmes with a view to eradicate malnutrition among children, pregnant and lactating Mothers in more than 25 centres based in our churches Islandwide.
4. Rainwater Harvesting for Church and Community living around our Church in BuonaVista, Galle. Training the women in the poor community in cultivation, basic dress-making, cooking etc., to generate income and improve their standards of living.

Mrs. Jessica Alles
President
Church of Ceylon Board of Women's Work
123 Anderson Road,
Dehiwala.
Sri Lanka.

5. Helping Parishes and Committees similar to ours within the church in their needs in safe drinking water, and construction and upgrading of sanitary toilets for the poor.

6. Organising Home Gardening Skills Workshops for Women's Associations in Sri Lanka in collaboration With the Department of Agriculture.

RAINWATER HARVESTING IN SRI LANKA:

In Sri Lanka, Rainwater Harvesting is not a new concept. Emphasis had always been given by our rulers of Ancient times to irrigation and conservation of rainwater in order to improve production of rice which is our staple food. History records that one of our ancient Kings, King Parakramabahu the Great, the 12th Century Architect of many water systems for Sri Lanka pledged that "NOT A DROP OF WATER FROM THE SKY SHOULD BE ALLOWED TO FLOW TO THE SEA WITHOUT BEING USED FOR THE BENEFIT OF MANKIND" One large tank built by him and named after him as Parakrama Samudra-[samudra meaning Ocean] still exists and its waters irrigate several acres much to the relief of our farmers. Yet another of our Ancient Kings in Sri Lanka, King Mahesan built the Minneriya Tank which is over 4650 acres in extent and irrigates several acres of land for cultivation even today. He was known as the GOD of Minneriya by the people. Many of our Village tanks are collections of water from small catchments. Over 30,000 tanks have been built in the Dry Zone.

THE BOUNAVISTA PROJECT:

In 1990, our Bishop and Archdeacon of Galle, informed us of the severe hardship the Church and Community in Bounavista were experiencing owing to scarcity of safe drinking water.

Members of our Board visited the Center which is 75 miles from our Head Quarters in Colombo and made a survey and discussed the problems with the village Headman. Heads of religious places of Worship in the village and the community.

BuonaVista probably got it's name from the early Dutch Settlers because of the panoramic view of the Galle Harbour and the Dutch Fort from the top of the Hill.

These were our findings and observations:

Buonavista is a rocky hillock projecting towards the sea, rising to about 90m above sea level. It's vegetation is mostly scrub jungle and coconut plantations and in extent is about 300 Hectares. There are about 95 families and 80 of them are very poor and live in thatched houses without the basic amenities like water and sanitary toilets. There are also many varieties of medicinal plants and also rare plants of interest to students of Botany. There had been for several years two deep wells about 75ft. in depth from which water was pumped to an overhead tank and used for domestic purposes. But from recent years it has been experienced that these wells run dry for nearly half the year and the water shortage becomes so acute that no activities can be carried on and all conferences and

seminars held in the building complex of the church are postponed for the rainy season. The women of the community had to trudge down the rocky hill for quite a distance for all their needs in water. As a result of there being no toilets, the whole area is polluted and the people suffer from bowel ailments. The number of settlers have also increased. There has been a lot of felling of trees and blasting and breaking of the granite rock for metal to be sold to the many quarries that have come up at the foot of the hill. It appears that all requirements for the Galle District is got from BuonaVista. All these may have combined to cause the natural water table to go below the stable levels as well as global atmospheric changes resulting in prolonged droughts which the people never experienced before.

SOLUTION:

We then consulted the National Water Supply and Drainage Board for advice. We were told that there was no hope of getting water from the main lines due to the high altitude. After a few tests, they said that 2 tube wells could be drilled and that we would then get uninterrupted supply of water and even in the severe drought conditions when all the wells in the locality have dried up, these tube wells will not fail in their yield. An estimate for the 2 tube wells was got and funds were made available by NORAD through the Water Supply and Sanitation Decade Service to which our organisation is affiliated. Two Tube wells, 250ft. and 180ft. deep below the ground were drilled and fitted with hand pumps as over pumping by an electric motor may result in intrusion of sea water. One of the pumps had to have a purification plant fixed to it as the water from that well had a high content of iron. Constant cleaning is necessary to ensure yield of pure water. we were also able to build 25 toilets for the families of the children who attend the Day Care Centre run by the Church. The Church and community were very pleased with the tube wells which functioned extremely well until the dry season came on when the water became a mere trickle. The water was naturally reserved for cooking and drinking and the community had to get water from elsewhere. The community also informed us that most of them were rid of their bowel diseases.

RAINWATER HARVESTING FOR BUONAVISTA:

Disappointed and desperate, I suggested Rainwater Harvesting from the roof cover of the building complex to our Archdeacon of Galle. The National Water and Drainage Board did not seem to have much knowledge about Harvesting rainwater from roof cover for household water supply. We spoke to our experienced engineer Mr. Lakshman Welikala who had served for several years in the Irrigation Department in the Dry Zone in water systems. He is a member of our Church in Galle. I had also been studying the magazine "Raindrop" which was sent to us by Mr. Dan Campbell of the former WASH Project of the USA. Mr. Welikala and I went through the magazines

very carefully and a project proposal for Rainwater Harvesting was submitted to the World Council of Churches. Funds were received and the construction work is in progress.

CLIMATOLOGICAL INFORMATION FOR GALLE:

Air temperature : -Highest observed : 92 F
Lowest observed : 71.9 F
Average temperature : 80 F

Relative Humidity Average : 86%

Rainy months : -SW monsoonal season: April, May, June.
:-NE monsoonal season: October, November
December

Drought periods : -Dry spells lasting to about 30 days
with very little rain is experienced
in the months of January, February,
March, July, August, September.

Average annual rainfall : 1450mm.

AVAILABLE YIELD FROM RAINFALL ON ROOF COVER.

Total area of roof cover : 1300 sq.M.
Average rainfall per month : 120.75 mm.
Total yield : 157,000 Lit.
Allow 30% for losses from waste due to
evaporation, absorption and over flow : 47,100 Lit.
Available Yield : 109,900 Lit.
50% of the roof cover will provide the
required yield : 54,950 Lit.

STORAGE TANK.

A Concrete storage tank is built on the ground close to the building complex to store 7000 gallons of water. The balance quantity of water will be diverted to a Reserve tank.

A Reserve Tank - a natural rock based pond 100 M. away from the storage tank was located. It was decided to convert it to an open Reserve Tank of capacity of 114,000 litres. All the excess water coming down on the S.W. monsoon will spill over to the Reserve Tank from the Storage Tank. The water from the Reserve Tank during drought will be pumped to the Storage Tank. An electric pump will be installed for this purpose.

The water from the Reserve Tank could also be used for the following purposes :-

1. Cultivation of cash crops such as pepper, coffee, ginger, mushroom, yams, lime, vegetables and leaves.
2. Cultivation of fruits such as pineapple, bananas etc.
3. Poultry, goat and dairy farm.
4. Breeding of fresh water fish in the open tank
5. Cultivation and preservation of medicinal and rare

plants that grow wild in the area. Cultivation will be done in the homesteads of the women and two acres of Church land. Funds for the cultivation has been made available by the American Women's Association - Colombo.

MARKETING:

A ready market can be found for all the produce as there are vast developments taking place in the vicinity such as:

1. Expansion of the Galle Harbour.
2. Tourist influx to the famous Unawatuna Beach.
3. The Free Trade Zone at Koggala.

COLLECTING SYSTEM:

The section of the roof of the building where rainwater is to be harvested has had to be fitted with P.V.C. gutters and down pipes.

COLLECTING TANK

Three collecting tanks of capacity 200 litres will divert the water coming from the roof to the control chamber.

DIVERSION:

All diversions will be in 15 cm. P.V.C. pipes and 22 cm. concrete hume pipes. These pipes will prevent any surface water seeping in.

CONTROL CHAMBER:

This is used to divert the first flow of rainwater from the roof before sending the water to the storage tank. A flush out system is designed to operate automatically in case of heavy rain and manually in case of low intensity rain.

SPILL WATER:

The excess water going in to the storage tank will spill over and will be directed to the reserve tank by a 22 cm. concrete hume pipe line.

BENEFITS TO THE COMMUNITY:

Water from both the storage and the open tank will be made available to the poor community from a separate tap. The model will be used to conduct awareness programmes to the community on rainwater utilization and encourage them to have their own units.

MAINTENANCE AND OPERATION:

The beneficiaries of the project who are mainly women will be trained to operate the switches and clean the

tanks specially before the monsoons set in. They will be taught methods of preventing breeding of mosquitoes and other insects and worms.

FILTRATION SYSTEM:

This will contain three tanks.

- * The first tank will aerate the water to remove any atmospheric acids dissolved in the water.
- * The second tank will be used for sedimentation and filtration with graded aggregates.
- * The third tank will be for chlorination to be done manually.

The abandoned well in the project area will be built up and sealed to store an additional 22,000 litres. Excess water from the Reserved Tank will be diverted for this purpose.

Rainwater harvesting from roofcover for Household activities is not practised in Sri Lanka. Water scarcity to householders is common everywhere and this may be due to the reduction of forest cover and construction of large scale reservoirs for hydropower. Impact in the environment is gradually felt all over the Island. This is evident in the shrinking of natural streams and water falls. Rain water harvesting seems to be a practical solution to all these. However since Rainwater harvesting for domestic use has not been practised in Sri Lanka we see another challenge to overcome peoples' prejudices in villages where people are used to well water, stand pipes and some times tube wells and never water collected from roof cover. Rainwater harvesting has many practical possibilities as this pilot scheme envisages. It is also a dream come true for the Board of Women's Work. We earnestly hope that our project in BunaVista will be a model for the future in Sri Lanka.

RAINWATER USE IN LIVESTOCK FARMING AND GARDENING

DR. MD. DAULAT HUSSAIN

ABSTRACT

A survey was conducted in coastal, forest and hilly areas to know the roof and gutter condition, storage method, type of structure use, cost of different sources of water use, water requirement and present status of homeyard farming.

Total and mean rainfall data of the study areas show that small dairy farming, poultry farming and gardening are possible and presently being practiced in the study area based on the availability of rainwater.

In Sundarban areas farmers have started homeyard farming, such as livestock rearing for milk purposes, poultry for egg production and garden for vegetable production. It has been reported by the farmers that homeyard farming is more profitable than the crop production in fields. Moreover, energy requirement in homeyard farming is less in comparison to field crop cultivation.

In forest and hilly areas ditches are dug to store rainwater for use in non rainy period. These ditches are also utilized for fish farming. Normally sing (*Heteropneustes fossilis*), koi (*Anabas testudineus*) and magor (*Clarias batrachus*) are cultivated in the ditches. Farmers rear about 50 to over 200 birds in homeyard poultry farms. Gourd, pineapple and different types of vegetable are grown in the hill sides and in forest area.

Professor, Department of Farm Power and Machinery,
Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

INTRODUCTION

The inhabitants of these coastal areas in Bangladesh have long time practical experience in using rainwater for domestic and non domestic purposes. The surface and underground water contain high percentage of sodium chloride. In coastal areas, hand tube wells, ponds water and even the green coconut give salty water. The author has made a survey in the coastal, forest and hilly areas to know the use of rainwater in different aspects.

Agricultural crop production in coastal area is much lower than the non salinic areas. Moreover, the availability of pure potable water is very acute. As a result people of that areas are compelled to collect and use rainwater for domestic and non-domestic purposes.

In hilly area there are acute problem of collecting water. People living there has to go some kilometers to fetch water which is very energy consuming job. Specially in dry periods(December to April) farmers of hilly area suffer a lot to feed water for their cows and poultry birds and watering in gardens. In this period water table goes very deep. Hand tube wells do not work and there is no any facility of central water supply system. That is why people in these areas have started to establish self supported rainwater catchment system to store and supply water for domestic and other consumption, such as water feeding to livestock and irrigation to small gardens. Because of present price and return of agricultural commodities, farmers are switching over very quickly to establish poultry farming, small dairy farming and gardening in homestead places and rooftops.

Considering the above facts in mind a study was conducted in some selected villages in coastal, hilly and forest area to collect information on the use of rainwater for livestock farming and small gardening.

The study included the following:

1. Field survey to know collection and storage practices
2. Cost of collection and future demand

FIELD SURVEY

Field survey was conducted in coastal area (a police station, Dacope, Khulna), forest site (Bhawal forest, Gazipur) and hill site (Khadimnagar, Sylhet).

Dacope, Khulna

Inhabitants of Dacope police station has longtime practice of collecting and storing rainwater. Normally earthen jar or old steel drum is used for the storage of rainwater. Rooftop discharge of

domestic houses is used for the collection of rainwater. Some rich farmers have started to store water in underground concrete tank.

Bhawal forest, Gazipur

In forest areas, people dig ditches for storing rainwater. Rainwater from rooftop and surrounding homeyard is collected in the ditch. This water is used for fish culture and also for domestic consumption and other necessary purposes.

Khadimnagar, Sylhet

In small hills where sloping is not very steep, people construct CGI sheet house. Normally at the top of the hill a single family lives. Rainwater is collected in the tank and then these water is supplied under gravity pressure flow to foot hill surroundings in small livestock farms and vegetable gardens grown in the slopes or in the foot hill. This practice is becoming very popular among the people living there and are getting a good return from farming. The vegetable gardens save the hill sides from erosion and collapsing due to rainfall and wind.

RAINFALL DISTRIBUTION

Some years (1991 to 1993) rainfall data are summarized in table 1. Rainfall data testifies that water requirement for all livestock farming and gardening are possible and water can be supplied throughout the year.

Table 1. Rainfall distribution in selected areas

Year		Mymensingh Town (mm)	Hilly area Khadimnagar (mm)	Bhawal Forest area (mm)	Dacope Coastal area (mm)
1993	Total	2724	4427	2707	1839
	Max	360	669	332	289
	Min	2	2	1	1
	Mean	129	177	104	79
	Sd	97	173	100	76
	CV	75	98	96	96
1992	Total	1538	3436	1281	1122
	Max	227	598	203	104
	Min	1	1	1	2
	Mean	69	118	53	53
	Sd	67	130	49	33
	CV	96	110	92	63
	Total	3182	4366	2650	1573
	Max	492	608	374	217

1991	Min	2	4	1	10
	Mean	132	167	94	68
	Sd	138	160	91	59
	CV	104	95	96	87

Source: Meteorological Department, Govt. of the peoples republic of Bangladesh, Dhaka.

ROOF CONDITION

The general roof conditions of houses are usually poor. The average family size in the area is about 6.1 which is higher than the average family size of 5.82 for Bangladesh as a whole (BBS 1987, Hussain, 1993). Most houses are thatched roof and only a small number use CGI sheet roof.

Table 2. Roof Condition in Selected Areas

Locations	Roof Condition		Area (m ²)
	CGI Sheet	Thatched	
Sundarban (Khulna) 20 families	10%	90%	25-40
Hilly areas (20 families)	5%	95%	10-32
Forest area (20 families)	-	100%	15-24

COST OF DIFFERENT SOURCES OF WATER

Table 3 shows a cost comparison of different types of water sources in Sundarban, Khadimnagar & Gazipur area. The cost was calculated on the basis of Consumption rate of 3 litre per person per day for a family of 7 members. Cost of drinking water, storage facilities, labour cost, wherever appropriate were also considered. Tax and Insurance costs were not included in the computation because these were not practiced locally. Straight line method was used in cost computation. The table indicates that the better quality of drinking water may be supplied either by rainwater Catchment method or by DPHE-UNICEF Sand filtered method. Rain water Catchment method was found to be more economic than the DPHE-UNICEF Sand filtered system.

Table 3. Comparative cost of different types of water sources in different area

Type of water sources	Average water cost (Tk/lit)		
	Sundarban (Dacope)	Khadim Nagar	Gazipur (Bhawal)
Pond	0.254	-	-
River	0.045	-	-
Canal/ditch	0.045	-	0.052
Rainwater			
a) Roof discharge	0.290	0.31	-
b) Open sky	0.300	0.315	0.311
Hand tubewell	0.285	0.295	0.290
DPHE-UNICEF Sand filtered facility	0.321	-	-

WATER REQUIREMENT

Water requirement depends on species, age and climatic factors. The ambient temperature has a marked effect on water intake. Bostauras cattle weighing 450 kg eating 10 kg dry feed per day drank 28, 41 and 66 litre of water a day when the temperature was 4, 21 and 32°C respectively (Maynard, et al. 1979). Poultry hen requires 0.5 litre/day, sheep for fattening 4 litre/day. Water requirement for poultry in litre equals to feed supplied in gms x 3 in high ambient temperature and feed supplied in gms x 2 in low ambient temperature. The average water requirement of livestock is shown in table 4.

Table 4. Water requirement for livestock

Class of	Summer at 30° (l/day)	Winter at 8° livestock (l/day)
Cow	55.00	30.00
Sheep	8.00	3.50
Goat	5.00	2.70
Hen	0.38	0.27

This water requirement is meant for drinking only and not for washing and cleaning the shed and animals. These results are obtained from five replications. These informations are important for the decision of designing storage structure of rainwater storage system.

Water requirement for some tropical crops and vegetables depends on ambient temperature, soil type and structure and type of crops or vegetables. The expected requirement of water for healthy growth of crops and vegetable (Biswas, et al. 1993) is shown in table 5.

Table 5. Irrigation demand of some tropical crops and vegetables

Crop/vegetable	Expected irrigation demand (mm)
HYV Boro	605
Aman	100
Wheat	250
Potato	200
Brinjal	400
Gourd	195
Cabbage/Cauliflower	175
Vegetables	70
Tomato	200
Long bean	150
Chilli	320
Mustard	160
Pea	90
Onion	175
Maize	24

HOMEYARD FARMING

Some innovative farmers of Dacope area have started homeyard farming. The trend of farming condition is shown in table 6. This practice is very limited among 5 percent farmers in the area. They constructed concrete tanks, gutters according to their own choice and not on the basis of scientific information.

Table 6. Present homeyard farming practices in selected areas

Tank Size (m ²)	Homeyard area (m ²)	Dairy cow (No.)	Poultry birds (No.)	Garden area (m ²)
50	1620	1	50	100
100	1800	2	100	150
150	2100	3	130	200
200	2400	4	150	250

In sundarban area, individual family those who have at least 3 acres of agricultural land, collect rooftop discharge of rainwater and store them in earthen jars and excess water of the roof discharge and water in the homeyard are collected in the underground concrete tank.

STORAGE STRUCTURE

Different storage structures are used such as earthen jars, concrete tank or ditches. Ten families were interviewed randomly. Rich people store rainwater in big earthen jars and in concrete tanks. Poor people do not store water for want of storage facility. The survey result is shown in table 7. Each jar has the capacity of 200 to 300 litres. The ditch capacity varies from 200 to 300 m³. Normally tanks are open and use this water for livestock and vegetable production. The construction cost varies from Tk. 10,000 to 20,000 (1 U\$= Tk. 40.00).

Table 7. Rainwater storage structures available with the farmers.

Location	Earthen Jars (No.)	Concrete tank size (m ³)	ditch size (m ³)
Sundarban area (10 families)	60	50 - 220	----
Forest area (10 families)	10	-----	200-300
Hilly area (10 families)	13	-----	250-290

DISCUSSION

During the survey period it was observed that two types of houses are constructed in the selected areas, such as CGI sheet or thatched roof houses. A few building was found in the selected areas. People are not rich and have land property from 2 to 10 acres. Farmers in the sundarban area are less interest in crop farming in the field due to low productivity level and farmers are interested to establish homebase farming like livestock farming or gardening. Water management for small poultry farm having 50 to 200 birds, dairy cows up to 4 to 5 and a kitchen garden having an area of 300 m² can be easily controlled smoothly from rainwater supply with the present system available.

In forest area, people collect water in ditches. They drink this water and for fish culture. They rear one to two dairy cows, 40 to 60 poultry birds and a small kitchen and fruit garden.

In hilly areas people collect rooftop discharge for drinking and overflows and side hill runoff are collected in ditch or tank for livestock and gardening. Hill slopes are used for vegetable production, pineapple production or tejpatha (bay leaf) production. Individual family rears 50 to 200 poultry birds. People in hilly

areas think that this type of farming is more profitable than rice or jute farming.

In terms of energy expenditure, homeyard farming requires less energy than the field work. Total net income is at least 3 times more than that of paddy or jute cultivation. Landless (agricultural land) farmers are mostly encouraged in this type of farming. Farmers are day by day getting interest to establish this type of farms. In general Bangladesh farmer has no work in idle periods. They remain idle and if they can establish homeyard farms, they themselves will remain busy throughout the year.

Social aspects of homeyard farming

1) Some farmers are interested for homeyard farming because women can be engaged in the farming work which in the field work is not possible.

2) It has been proved that homeyard farming is more profitable than the field cropping and less energy is required. Standard of living will raise.

3) During rainy season, farmers have no work in the field and at that period they can put their time in the homeyard farming. Moreover, they will remain busy in managing rainwater collection and its storage.

4) About 60% villagers in the sundarban area and 40-60 % in hilly and forest areas are interested to establish homeyard farming if bank loan with a very low interest rate is available.

Suggestions and recommendations

1. This study was conducted in limited time and in areas. A systematic study on the benefit of homeyard farming will generate informations for planners, decision makers, NGO's for proper establishment of homeyard farming.

2. Landless and jobless educated people may be utilized by creating facility of homeyard farming and the dependency on government or private jobs may be reduced. Government helps in this respect may solve the problem.

3. Women or men of the household should be trained regarding the homeyard farming and method of rainwater collection. Regarding the establishment of rainwater based homeyard farming, no significant number of unwillingness was observed. The number of homeyard farms will increase day by day as the farmers will know the positive benefit of homeyard farming.

4. The stored water should be free from contamination and time to time the water should be tested for its degree of useability for animals or human consumption.

5. Sometimes frogs are found living in the tank. A good cover in the tank and jars may solve the problem.

6. Ferrocement (wire-mesh-reinforcement), bamboo reinforcement concrete tank may be constructed for the storage of rainwater. Bamboo is easily available in Bangladesh.

7. Rainwater based homeyard farming should be encouraged by an organized way (Govt. level).

8. Bacteriological analysis should be done periodically to assess the quality of water.

Acknowledgements

Farmers of Dacope, Khadimnagar and Bhawal areas are acknowledged greatly for cooperation and assistance during the survey work. Thanks are also due to Bangladesh Agricultural University Research System for financial support to conduct this survey work.

References

- Maynard, L.A.; Looli, J.K.; Hintz, H.F. and Warner, R.G. (1979): Animal nutrition, Seventh TMH edition, pp.54.
- Bangladesh Bureau of Statistics (1987): Statistical Year Book of Bangladesh, Government of the Peoples Republic of Bangladesh.
- Hussain, M.D.; Ziauddin, A.T.M. (1992): Rain water harvesting and storage techniques from Bangladesh, Water lines, 10(3): London.
- Hussain, M.D.; Ziauddin, A.T.M. and Ali, M.R. (1988): Rainwater use in Bangladesh- A case study in Dacope upazila, Research report No. 8, Department of Farm Power and Machinery, Bangladesh Agricultural University, Bangladesh.
- Biswas, M.R.; Mondal, M.A.S. (1993): Irrigation Management for crop diversification in Bangladesh, pp. 223-225, The University Press Limited, Dhaka, Bangladesh.

**Building Pond for Harvesting Hillside Rainwater:
an effective solution to the problem of drinking water supply**

Tang Kuisheng Liu Fuying

(Dept. of water Conservancy and Hydropower, Hunan Province)

Tan Shiqing

(Bureau of Hydropower, Shimen County, Hunan Province)

Building pond for harvesting hillside rainwater is an old-aged and developing water conservancy technique. It is used not only for domestic water supply, but also for traditional irrigation. In view of the natural features of the arid areas in Hunan Province, it is proved by analysis and discussion on water quantity, water quality and engineering techniques etc. that harvesting hillside rainwater is an effective approach for solving the potable water problem in rural areas. Based on the long term practice of the actual operation, successful experience has been obtained.

Key words: arid area, harvesting hillside rainwater
solution to the problem of potable water.

I. The fundamental features of building pond for harvesting hillside rain water

Analysis on the characteristics of the geographical location, hydrometeorological conditions, geological conditions and the benefit of a engineering built for domestic water supply all should be carried out.

1. Geographical location and hydrometeorological condition

(1) In general survey of water sources, more attention should be paid on inquiring into the local masses, especially on the observation data about water consumption and capillary water content made by rural household women, and through whom, it is confirmed whether capillary water overflowed on a sloping surface in a severe drought year.

(2) Slopes chosen as the basins for rainwater harvesting should meet following requirements: there is no polluted water sources, large grottoes and funnels in the slope. It has a good vegetation. The hill body is steady and rain water in the slope can be collected and harvested.

(3) Relatively high position of pond and proper distance between pond and user are required. It is of great advantage to develop tap water pipes for domestic use as move as possible.

(4) It is also required for pored location with good geological condition, and taking advantages of obtaining raw materials on the spot in the light of local conditions, making a good use of natural pits and small tanks by enlarging and rebuilding against permeability to reduce engineering quantity and decrease engineering cost.

(5) Drainage hole for flood discharge must be constructed of a finished, pond.

(6) Hydrometeorological data should be gathered accurately. For an important projects, frequency analysis of annual average rainfall and runoff should be carried out based on hydrometeorological data, and appropriate representative year (P)% is singled out for standard design.

2. Determination of pond volume

Determination of pond volume depends on the quota of human drinking water and the scale of water supply system in rural areas. In a country, the quota is different in different periods. Based on the data concerned, in Japan, it was 42 liter per capita each day (LPCD) in 60's, 70-110 in 70's and 115 in 80's. In China, the criteria of drinking water varies from one district to another. For example, in rural areas of Shaanxi province, the quota of drinking water is 10-30 LPCD for human and 30-50 LPCD for livestock. In these regions of severe water shortage " in Hunan Province, it is 40 LPCD for human and 20-50 LPCD for big livestock with assurance frequency of 75 %, which means that drinking water can be supplied even if there is no rain continuously for 60-70 days .

As the project of "drinking water supply for Human" is constructed in rural areas of Hunan province, the quota of water consumption is commonly calculated simply. Only the number of people is involved in calculation, (the number of livestock is not taken into account,) and in which the quota for human is raised up to 80 LPCD.

Maximum of daily water consumption (Q_R)

$$Q_R = 0.1 \times N \quad (\text{m}^3/\text{day}) \quad (1)$$

N——Stands for the number of people

Average daily water consumption (Q_{av})

$$Q_{di} = Q_R / K_r \quad (\text{m}^3 / \text{day}) \quad (2)$$

Where, K_r -coefficient of daily variation, In general it is 2-4.
Annual average water consumption(W)

$$W = Q_{di} \times 365 \quad (\text{m}^3) \quad (3)$$

(1) Calculation of monthly water consumption

After the calculation of annual average water consumption, the water consumption in each month is different and changes month by month. In general, it is larger during the period with high temperature in summer, and smaller in winter, its coefficient of monthly change K_m equals to 1.5-2.0,

Table 1. Monthly water consumption from a project

$$K_m = 1.62$$

Mouth	1	2	3	4	5	6	7	8	9	10	11	12	whole year
monthly percentage	3.12	5.99	5.08	4.11	9.94	11.31	13.47	12.14	10.53	9.95	9.21	5.21	100%

Monthly water consumption (W_m)

$$W_m = W \times P \quad (4)$$

Where, P is monthly percentage. Based on the assurance frequency of 85%, and according to the investigation and analysis of the situation of villager' water consumption, monthly percentage (P) in Table 1. is determined. And its value is related to monthly air temperature. When there is not enough data for calculation of P , it also can be worked out in the light of the change process line of the local normal highest average of month air temperature.

(2) Designed water supply

Mainly based on the local hydrological data, which should be consistent and representative, designed water supply in each month can be worked out by frequency analysis, determination of the representative year, calculation of monthly water supply and the area ratio of rainwater harvesting basin of built pond.

Monthly water supply W_{ms}

$$W_{ms} = R \cdot T \quad (m^3) \quad (5)$$

Where, R stands for runoff. T represented the length of time. W_{ms} also can be worked out by the product monthly designed water supply in the whole year.

(3) Pond regulating Volume

- a. An accurate calculation method of regulating Volume.

Calculation of pond regulating volume is based on monthly water supply and water consumption. The negative accumulate value of the difference between monthly water supply and water consumption is just the regulating volume of pond.

Due to the uneven distribution of hillside flow in space and time, it could not meet the actual requirement to determine regulating volume merely by water consumption for Living. Evaporation and seepage also should be taken into account.

- b. A simple method for calculating regulating Volume.

A set of empirical data has been obtained from many engineering tests, and it is appropriate to be applied to the small-scale project without the local hydrological data. It is simple and easy to be used by people who engage in water conservancy at the basic level.

The expression is :

$$V = M \times 0.1 \times N \quad (m^3) \quad (6)$$

Where, V---- pond Volume (m^3)

0.1--- the quota of drinking water (m^3 per capita each day)

M----- the number of continuous dry days during which drinking water can be supplied.

N----- the number of people

The range of M is determined by the flow condition in the slope. In general, M varies from 50 to 2000, and it is bigger when there isn't capillary water in the slope. Combined with irrigation project, the amount of water demand for irrigation should be increased.

M can be determined by following empirical formula:

$$M = M' \times (1 + \eta\%) \times \frac{1}{C} \quad (7)$$

$$M' = \frac{2.5720164}{2222} \times \frac{A}{B} \times 10^5$$

where, $\eta\%$ --- per cent of the total loss

C --- Coefficient of water use

A --- the quota of drinking water for human

B --- assurance frequency

In general, $\eta\%$ is 10%, which mainly include evaporation and seepage; the assurance frequency of drinking water supply is 75-85% (equivalent to 60-70 continuous dry days); coefficient of water use is 0.8-0.9 the range of drinking water quota is 0.05-0.1 m³ per capita each day, and the average is 0.065 m³ per capita each day.

The relation of water balance is actually reflected in above calculation method. That is, when rainwater is harvested from a given slope there must be a pond with a enough volume to ensure the drinking water supply for the designed number of people.

It is :

$$V = \frac{W}{\beta} \quad (8)$$

Where, β --- the number of re-storage times, it is in direct proportion to the area of hillside for harvesting rainwater, and in inverse proportion to assurance frequency and the number of people. the expression of β is:

the expression of β is:

$$\beta = \frac{H}{M} \times \frac{S}{N} \quad (9)$$

Where, S --- area of the slope

N --- the number of people

coefficient of pond regulating volume (ϵ)

$$\varepsilon = \frac{1}{\beta} \quad (10)$$

Generally, it is appropriate for the area of hillside to be 50-100 m² per capita. The amount of harvested rainwater from the area of hillside can be calculated by following formula:

$$W = S \times Q \times K \quad (11)$$

Where, W----- amount of harvested rainwater (10000 m³)

S----- area of hillside for rainwater harvesting (km²)

Q----- normal average of water yield < 10000 m³/km²)

K----- conversion coefficient of hillside area. Commonly, it is 0.8, equivalent to 35-40 the slope of.

In the arid region of province, normal average of W is 500000 m³/km² commonly, So, pond volume can be also calculated by following expression:

$$V = \varepsilon \times S \times K \times Q \quad (12)$$

Where, V----- volume of pond (10000 m³)

Q----- normal average of water yield (10000 m³/km²)

E----- coefficient of pond regulating volume. In general, $E \leq 0.5$.

II. Flood Calculation

The project of rainwater harvesting from hillside for drinking water supply should be both economical and safe. During the course of project design, flood must be taken into account. Flood discharge gate should be built in front of pond, and a pond should have spillway. The formula for calculating flood volume is:

$$W = (H_{24} \cdot K_p \cdot \delta - I_0) \times F \times 0.1 \quad (1000 \text{ m}^3) \quad (13)$$

Where, H₂₄-- rainfall in 24 hours. In province, it is commonly 100-110 mm;

K_p---- flood frequency, modular coefficient of Pearson type III distribution, It is determined by C_v and P(%) in special table, When P(%) is 3.33 K_p is 1.5-2.5;

δ---- 1.0;

I₀---- rainfall in early stage, it is 25 mm;

F---- area of hillside using for rainwater harvesting (km²);

0.1--- conversion coefficient

1. Simplified calculation formula of flood peak discharge

$$Q_m = \frac{W \times A_0}{8.64} \text{ (m}^3/\text{s)} \quad (14)$$

Where, W---- flood volume (10000 m³)

A---- Variation coefficient of storm in twenty-four hours in local rain pattern demarcation. It is worked out by analysis and statistical figures of many typical cases. Its value is shown in Table 2.

Table 2. Storm variation coefficient in different demarcation in Province.

Storm demarcation	A ₀	Storm demarcation	A ₀	Storm demarcation	A ₀
region 1	3.97611329	region 4	3.573144867	region 7	3.836353889
region 2	3.55555556	region 5	3.826437941	region 8	3.690510949
region 3	3.672639226	region 6	3.859541985	average	3.74872090

2. Calculation of Pond's spillway size

Size of spillway channel should be designed according to its discharge (Q'). Because of the small storage of pond in the domestic water supply project, which is generally less than 1000 m³ and with a quite small regulation capacity, So, Q' can be regarded equal to Q_m.

Due to much restriction on rainwater harvesting from hillside, the overflow depth is thin and its form commonly belongs to that of wide crest of spillway. So, flood discharge Q' is worked out by following hydraulic formula:

$$Q' = Q_m \quad (15)$$

$$Q' = \varepsilon \cdot m \cdot b \cdot h^{3/2} \quad (16)$$

Where, ε --- side contraction coefficient. In general, it is 0.9;

m---- discharge coefficient, it is commonly 1.5;

h---- depth of overflow, In general, it is limited to 0.15-0.35 m;

b---- width of spillway crest. It approximately is $8.28 Q_m$ (m).

Since domestic water supply is generally satisfied by rainwater harvesting from hillside, and the project scale commonly is small, flood peak discharge can be directly used as the inflow rate in the design of channel section.

III. Sedimentation Tank

In order to harvest rainwater in flood season, flood release gate must be built in the inflow channel, and sedimentation tank should be built in front of pond to reduce the turbidity of flood water.

1. Width of sedimentation tank:

$$B = \frac{Q_m}{V_{rop} \cdot H_o} \quad (17)$$

Where, B---- width of sedimentation tank (m);

Q_m --- designed flood peak discharge (m^3/s);

V_{rop} --- average flow velocity in sedimentation tank c In general, it is 0.2-0.3 m^3/s ;

h_o ---- flow depth over silt layer is sedimentation tank (m);

$$h_o = \frac{Q_m}{b \cdot V_p} \quad (18)$$

where, b---- width of inflow channel

V_p --- flow velocity in soil channel, it is limited to 0.5-0.6 m/s;

$$h = t + h_o + \Delta h \quad (19)$$

Where, t---- depth of silt layer in sedimentation tank ,it is 0.1-0.15 m

h---- excess height, which is 0.15-0.2 commonly.

2. Time for Sedimentation (T)

$$T = \frac{h_0}{W - \delta V_{rop}} (S) \quad (20)$$

Where, h_0 ---- flow depth over silt layer in sedimentation tank (m);

W ---- Sedimentation velocity of suspended sand, which is related to sand diameter, In project for drinking water supply, the permitted value of sand diameter is no more than 0.02 mm ($d \leq 0.02$ mm). In general, W is 0.029-0.0015 m/s;

δ ---- ratio of sedimentation velocity to average flow velocity. Generally, it is 0.04-0.2.

3. Length of Sedimentation Tank (L_1)



Figure 1. sketch map of sedimentation tank

$$L_1 = T \cdot V_{rop} (m) \quad (21)$$

4. Length of the Gradually Changing Part (L_2)

$$L_2 \approx (3-5)h_0 (m) \quad (22)$$

size of inflow channel;

$$bh_0 = \frac{Q_m}{V_p} \quad (23)$$

IV. Requirement of Sanitation Facilities

In the pond, which is specially used for drinking water supply, fish culture is not permitted, and afforestation and grass seeding in the slope from which rainwater is harvested

are necessary. Moreover, drainage ditch and brick wall with height of 0.3-0.5 over ground should be constructed around the pond. Additionally, necessary filtrating facilities, chemical purification, regular silt clearance, and water quality monitoring and management by special workers should be carried out.

Especially during the high-water period, it is inevitable that sand is brought into pond. As a result, the turbidity of pond water is high, and in general, it takes 3-4 days to become clear by gravity settle.

In order to ensure pond water of good quality, it is indispensable to build facilities of filtration and purification in pond. Generally, slow-filtration tank is used for purification as shown in Figure 2.

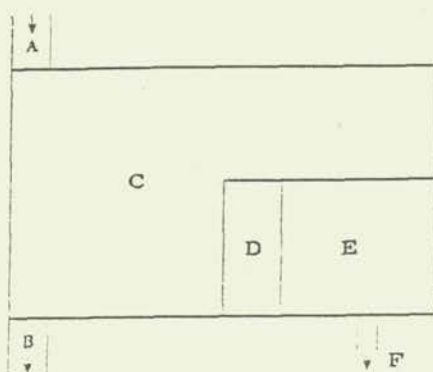


Figure 2. plane diagram of pond.

- A----inflow channel
- B----spillway channel
- C----pond storage
- D----slow-filtration layer
- E----purified tank
- F----pipe line for water supply

1. Installation of the Slow-filtration Layer

In general, vertical slow-filtration layer is installed in the regulation pond.

The first layer of filtration which get in touch with the purified water is paved with filter net; the second layer with fine sand, thickness is 0.5-0.8, sand diameter is 0.3-1 mm; the third with coarse sand and small pebble, thickness is 0.2-0.25 m, diameter is 1-8 mm; the fourth with

charcoal, thickness is 0.3 m; the fifth with big pebble, thickness, is .15 m, diameter is 8-32 mm. In general, through the above filtration layer, water quality can meet requirement.

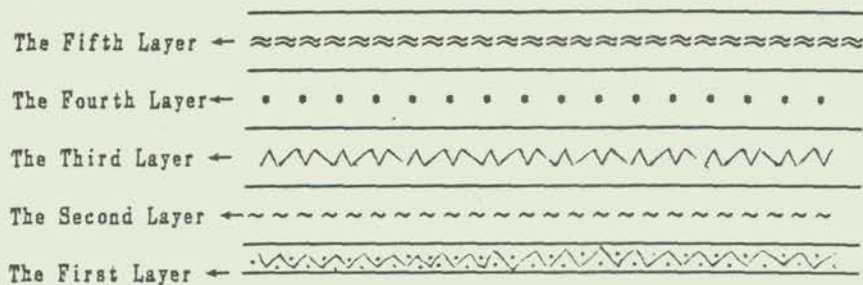


Figure 3. Sketch Map of Filter Layer

2. Area of Filter Layer

Area of filter layer is determined by the maximum of water demand (m^3/h) in a day with the largest water requirement (m^3/d). The velocity of filtration is 0.1-0.3 m/h.

Area of filter layer:

$$W = (Q_R / 24) \frac{K_s}{\mu} = \frac{\mu \cdot K_s \cdot Q_R}{24} \quad (24)$$

Where, W --- area of filter layer (m^2);

Q_R --- the maximum of daily water supply (m^3/d);

K_s --- Coefficient of variation in time .It is generally 4-6 in rural area.

μ --- filtration velocity It is 0.1-0.3(m/h);

V. Conclusion

Building pond for rainwater harvesting from hillside is an effective solution to the problem of drinking water supply in arid area where peasant households distribute in a decentralized way and water resources is in sever shortage. During "seventh-Five"period, funds of 1184900 Yuan has been invested in Shimen County, Human Province, 715 hydraulic works have been built, and the problem of drinking water supply for 41931 people has been solved, of which 54% should attributed to rainwater harvesting form hillside. Operated for ten years, it is proved that it has a good effect.

Roof Rainwater Harvesting System in Changdao County and Analysis on Its Ecological benefits.

Sun Fuwen

(Dept. of Water Conservancy, Shandong Province)

Zhou Qiyun, Liu Yulu

(Water conservancy office, Changdao County, Shandong Province)

Roof rainwater harvesting engineering in Changdao county, which is devolved from Chinese water Conservancy Ministry to Shandong Province, is an experimental project. After three-year's hard work, It has been almost accomplished completely.

1. Physiographic Survey

1.1 Geomorphology and Topography

Changdao County locates at the joint place between the Bo Sea and the Yellow Sea. Which is the only one island county in Shandong Province and consists of thirty-two islands. There are eight townships, two towns in Changdao county. The total area of the county is 56 km² with a population about 43000. The area of its biggest island, Changshan Island, is 13.43 km², while that of the smallest one, Xiaoshan Island is merely 0.0008 km². Land forms on these islands is characterized by undulating mountains and cross valleys. In the north part, steep banks face deep sea water, and isolated peaks stand out from sea, while in the south part, islands scatter all over like stars in the sky and ninety-nine bay and gulfs with fine scenery have been formed.

1.2 Hydrometeorological Condition

The local climate of Changdao County belongs to temperate monsoonal continental climate, which is featured of clear and distinct seasons, frequent strong wind in spring and Winter, being rainy and cool in Summer and Autumn. Its annual average rainfall is 520.9 mm which is more in the south part and less in the north part with an uneven distribution in time. About 70% of the whole annual rainfall is concentrated in flood season.

1.3 Situation of water resources

In order to solve the problem of water shortage, overall countermeasure which consists of storing, pumping, conserving and water management is put into practice. By the end of 1993, two small reservoirs, forty-two ponds, one hundred and fifty five motor-pumped wells and large-mouthed wells have been completed. The capacity of water storage projects reach 850000 m³ and the area for water-retaining accounts for 35 % of the total of Changdao country, by which the runoff flowing into sea in flood season is greatly reduced and groundwater is effectively conserved and replenished. According to <<The Long-term Program of Water Supply in Changdao Country>>, in 1990, the annual water shortage in the entire county will be 1318000 m³ on condition that P=95 %. Along with the development of national economy, the contradiction between water supply and water requirement will become more severe. Not only orchards can not be watered any more, but also the normal water consumption for human and livestock will become very hard to meet. The population of the whole county which is suffering from water shortage reaches 22000, accounting for 50 % of the total population. It is larger in a drought year, and water crisis and water affairs increase rapidly. Water shortage has already affected people's life on the island and greatly impeded its economic development.

2. Roof rain water Harvesting project

Roof rain water harvesting project consists of five parts. roof area for rainwater harvesting, water conveyance, filter, water storage and water supply system.

2.1 Roof area for rainwater harvesting and the quantity of water supply.

There are three kinds of dwelling roofs in Changdao County: the first kinds is shaped roof, the second is flat concreted roof and the third is integration roof (that is the combination of Λ -shaped roof and flat concrete roof).

Based on perennial average rainfall, roof's runoff coefficient and the quota of water consumption, the required area for rainwater harvesting to meet the annual water consumption of each people can be worked out. The results of calculation is shown in Table 1. At present, the area of dwelling roof is generally 60-130 m², which is enough to meet the requirement for rainwater harvesting.

Table 1. The required area of different roofs for rainwater harvesting

	A-shaped roof	Flat concrete roof	integration roof
50	15.0	13.0	14.2
75	18.3	15.9	17.3
95	24.3	21.1	23

2.1.2 Determination of runoff coefficient

According to experimental data, due to the different kinds of roof area for rainwater harvesting, their run off coefficients are also different. It is 0.68 for ^ - shaped roof 0.78 for flat concrete roof and 0.72 for integration roof.

2.1.3 Calculation of water supply amount

The quantity of water supply by roof rainwater harvesting can be worked out by following calculation formula:

$$W = H \cdot S \cdot \frac{C}{1000}$$

Where, W---water supply amount (m³)

H---rainfall (mm)

C---runoff coefficient

S---roof area for rainwater harvesting (cm²)

The results of calculation are shown in Table 2, Table 3 and Table 4.

2.2 Water conveyance system

Water conveyance system consists of three parts: water collecting channel, water-falling tube and water conveying pipe. Its function is to transport the harvested rain water from roofs to an usable structure which is used for water storage.

Table 2. The Quantity of Water Supply from $\wedge$ - Shaped Roof

	10	20	30	40	50	60	70
60	0.408	0.816	1.224	1.632	2.040	2.448	2.856
80	0.544	1.088	1.632	2.176	2.720	3.264	3.808
100	0.680	1.360	2.040	2.720	3.400	4.080	4.760
120	0.816	1.632	2.448	3.264	4.080	4.896	5.712

Table 3. The Quantity of Water Supply from Flat Concrete Roof

	10	20	30	40	50	60	70
60	0.468	0.936	1.404	1.872	2.340	2.808	3.276
80	0.624	1.248	1.872	2.496	3.120	3.744	4.368
100	0.780	1.560	2.340	3.120	3.900	4.680	5.460
120	0.936	1.872	2.808	3.744	4.680	5.616	6.552

Table 4. The Quantity of Water Supply from Integration Roof

	10	20	30	40	50	60	70
60	0.432	0.864	1.296	1.728	2.160	2.592	3.024
80	0.576	1.152	1.728	2.304	2.880	3.564	4.032
100	0.720	1.440	2.160	2.880	3.600	4.320	5.040
120	0.864	1.728	2.592	3.456	4.320	5.184	6.048

Section design of water collecting channel is based on such principle that rainwater can not overflow the channel even with the maximum of rainfall. Channel with rectangular section is generally made of thin sheet of Zinc-plating. Its bottom width is 8 cm, inner side height is 7.5 cm and outer side height is 8 cm. Channel with U-shaped section is commonly made of tubular product of nonpoisonous PVC, Its diameter is 125-150 mm. When a tubular product is lengthwise cut up into two same part, two semi-circular channels are formed Both water-falling tube and water conveying pipe are made of tubular product of PVC.

2.3 Filter system

Filter system is essential for rainwater purification, Generally, in one end of a dwelling room, a water tank which is 50 cm long, 50 cm wide and 100 cm high is built under foot of one room wall: Water conveying pipe is buried at the middle part of tank bottom and filter materials are placed in the tank. Filter material, which is made up of clean pebbles, coarse sand and active carbon etc, is arranged from bottom to upper in a proper order shown is table 5. Different filter materials are separated by close nets, which facilitate the replacement of filter material.

Table 5. Arrangement of filter materials

the first group			the second group		
name of filter material	diameter (mm)	thickness (mm)	name of filter material	diameter (mm)	thickness (mm)
pebble	30-50	100	pebble	10-30	150
pebble	10-30	100	round gravel	2-5	150
round gravel	2-5	100	active carbon		150
extreme coarse sand	2	100	extreme y coarse sand	2	150

It is proved by experiment that the second group of filter materials has the best effect of rainwater purification.

2.4 Water storage system

2.4.1 Location of cistern

Location of cistern should be far from toilet, poultry pen and other sits where toxic substance or polluted material is placed. Meanwhile, the convenience for use and management also should be taken into account. It would be better build it in yard, rear yard or in kitchen.

2.4.2 Cistern's Volume

Cistern's Velum is comprehensively determined by following factors: the situation of

water shortage, area of roof for rainwater harvesting, the number of family people and the quota of water consumption, Taking Hu Zaixian, a family for experiment, as an example: a round cistern with a volume of 10 m^3 is built, the number of family (there are three people in this family) people is three and the daily quota is 15 kg for each person, According to the statistical data of precipitation from June 29, 1991 to June 29, 1992, the total actual rainfall in the whole year is 335.6 mm, which approaches to the assurance frequency of 95 % ($P=95\%$). During the year, rainwater was harvested and used simultaneously, and the daily water consumption was registered. The statistical figure shows that the actual accumulative water storage in the whole year was 17 m^3 , which is equivalent to that the cistern was used is circle for 1.7 times, and the water supply from harvested rainwater is completely enough to meet the family's water requirement for living. Additionally, combined with the real statistical figures of water consumption from another four experimental families, the optimum Volume for cistern is worked out as 10-15 m^3 .

Cistern has two kinds of form, One is round and the other is rectangular. Both the round and rectangular can be fashioned into three pattern: underground, semi-under ground and must be free from seepage and leakage.

2.4.3 Purification-and sterilization

Before rainwater is conveyed into cistern, it flows fist through filter tank, by which the total bacterial index is reduced by 60%, about 50%-94% of coliform bacteria can be filtered away and the turbidity completely satisfies the international standard. Although most of the impurity and bacteria are removed away by filter tank, there are some bacteria still flowing into cistern. Therefore, sterilization is still necessary for rainwater in cistern. In general, bleaching powder or highly effective disinfectant is used as bactericide, which is put into cistern is accordance with the proportion 10 g/m^3 and then stirred up completely. Bactericidal agent is put into cistern only once a month in winter and spring, and twice a month in Summer and Autumn. It is enough for sterilization and the rainwater after treatment completely meets the water standard for living.

2.5 water supply system

In order to ensure rainwater in cistern free from recontamination bacteria, microorganism, as well as some toxic substances, the cover of cistern's water-taking hole should be opened as less as possible, and water-baking tools should be under a good care for the special use. Commonly, mini-submerged motor pump, hand-pressed pump and special barrel are used as water-taking tools. On the flat top of single-story house, a small tank with a volume of 1 m^3

is built and rainwater is pumped up to the tank from cistern by mini-submerged motor pump for kitchen use and bath use. So, domestic tap water supply is realized.

3. Beneficial analysis of rainwater harvesting project

3.1 Project investment

Changdao County is an island county, Most of the building materials are purchased from outside. Therefore, project cost is higher-than-that in inland. Taking Xiaoheishandao, a village used as experimental site, as an example; there are sixty five families and sixty five cisterns in the village. Each cistern has a volume of 10-12 m³. The average roof area of each family for rainwater harvesting is 80 m². Each family whose rainwater harvesting system is equipped with water collecting channel has invested about 1500 Yuan and those without water collecting channel (making a use of the eaves of their single-story houses) have invested about 1300 Yuan each. The entire investment of the village is 93720 Yuan and the average investment of each family is 1442 Yuan. According to calculation, the total investment can be taken back completely in two years after operation.

3.2 comprehensive beneficial analysis

3.2.1 Effective solution to the problem of water supply for living of fishermen.

According to the statistical figures of the experimental village, Xiaoheishan, in 1992: there are altogether sixty five cisterns in the village. The actual annual water storage is 1625 m³. In a normal year, cistern is used in cycle for 2.7 times and the problem of water supply for living and production of all people in the village is solved. Brought along by the experimental village, 2500 cisterns have been constructed in Changdao County. The total annual water storage reaches 65000 m³ and the problem of water supply for living of more than 30000 people is solved. Converted into money in accordance with the cost of desalination of sea water, which is 10 Yuan/m³, it is equal to 650000 Yuan. Utilization of rain water resources is an effective and sustainable solution to the problem of water supply for living of the island fishermen in virtue of its small investment, quick effect, convenience, safety and reliability.

3.2.2 Amelioration of sanitary condition and promotion of the general level of the people's health.

Fishermen on these islands have suffered from saline water for quite a long time. So, their physical health has been seriously affected. In general, they have (suffered from) high

blood pressure and poor liver function. Give an example, in Xiaoyindao village, according to physical examination, none of the people in the village was qualified for being a soldier for quite a few years. However, since the project of rainwater harvesting has been widely popularized, the condition of potable water supply has been greatly improved and the condition of potable water supply has been greatly improved and people's physique become healthy and strong. In 1993, two young people of the village were up to standard and joined the army after physical examination. Additionally, boiler and barbershop is placed in the village, and most of the families have installed solar shower machine. Bath or shower is available after labor. So hygienic habit is changed and the level of people's health is raised.

3.2.3 Liberation of labor force and promotion of economic development

According to investigation, it takes each family of fishermen two hour a day to solve the problems of living water. After the project of rainwater harvesting was widely spread, there is no worry of fishermen about portable water and about 1000000 labor days are saved each year. There fore labor force is concentrated on the development of fishing, cultivation of kelp and shellfish etc. Merely depended on this term, the in come of the whole county is rained by 3310000 Yuan each year and fishermen's income is also increased, the villages economy has a rapid development.

3.2.4 Rain water utilization promotes the development of all trades and professions.

Rain water use has created favorable conditions for all trades to develop. For examples, in Xiaoheshan village, since rainwater has been harvested and used as the source of potable water, each year 100 m³ fresh water of two original wells is saved and used for freezing procession of aquatic product. Calculated in accordance with the water consumption for each 1000 Yuan, which is regarded as 0.74 m³, it creates profit 1350000 Yuan and tax 220000 Yuan every year. In Moshizui village on Tuozi island, two cold storage plants have accomplished rainwater use system and directly use rainwater for freezing aquatic product, and put an end to history of fresh water which is shipped from outside. In the woollen mill of Changdao county, rainwater is also used as cooler and the annual rainwater supply is 500 m³. Calculated according to water consumption for each 10000 Yuan, which is regarded as 4.74 m³, it creates profit 105000 Yuan and tax 150000 Yuan each year. In the county town, some institutions and factories have constructed sixty rainwater harvesting systems. The largest one among them has a volume of 300 m³, The total volume of the sixty projects reaches 2522 m³ and the annual average accumulative water storage is 9000 m³, which is used in all trades and professions for living or production, and the problem of water shortage is also mitigated.

3.2.5 Developing courtyard economy and improving ecological environment.

Due to the deficit of fresh water on islands, fishermen have not the practice of planing. Vegetables for meals are all bought from inland. Rainwater not only solves the problem of water supply for living, but also provides fresh water for cultivation of flower and vegetable in or out of courtyard. Furthermore the surplus of rain water, is also used for irrigation. So courtyard takes a new look of green and is filled with fruits and fragrant air. The average yield of vegetable for each family is more than 200 kg, which is not only provide fresh vegetable throughout the year, but also beautifies the environment. In the town proper, seven projects of rainwater harvesting of road surface have been constructed by the county's building committee. The total volume is 830 m³ and the annual accumulative water storage is 2100 m³, which supplies fresh water for street's afforestation. Only in afforestation, water change 20000-30000 Yuan is saved every year. In many institutions such as the county's museum and woolen mills etc. road surface is courtyard is used for rainwater harvesting. It not only provides fresh water for temporary production, but also supplies fresh water for watering flowers, lawns and trees. So, courtyards become ever-green and these institutions are conferred the title "garden unit". Rainwater use promotes the afforestation of the town proper, improves. the ecological environment and makes these islands become more beautiful.