BIBLIOGRAPHIC DATA SHEET	1. CONTROL NUMBER PN-AAJ-011	2. SUBJECT CLASSIFICATION (695) AP10-0000-G730

3. TITLE AND SUBTITLE (240)

Watercourse improvement research in Pakistan

4. PERSONAL AUTHORS (100)

Kemper, W. D.; Clyma, Wayne; Skogerboe, G. V.; Trout, T. J.

5. CORPORATE AUTHORS (101)

Colo. State Univ. Engineering Research Center

6. DOCUMENT DATE (110)	7. NUMBER OF PAGES (120)	8. ARC NUMBER (170)
1980	106p.	PK631.7.K32a

9. REFERENCE ORGANIZATION (130)

Colo. State

10. SUPPLEMENTARY NOTES (500)

(In Water management technical report no. 56)

11. ABSTRACT (950)

Loss of almost half of the water from watercourses was identified as a primary waste of irrigation water which is a limiting factor in crop production in Pakistan. Physical causes of the loss were identified as: (a) high porosity of upper portions of the banks due to burrowing activities of rodents, insects and worms; (b) thin fragile banks near junctions due to borrowing of soil for weekly construction of dams; and (c) rising levels of water in the watercourse due to vegetative growth and sedimentation. Difficulty in organizing farmers to accomplish regular cleaning and repair was identified as an underlying sociological cause of the loss.

Experimental masonry and concrete watercourses were built by the government for the farmers. They were too expensive and required too much cement to provide a nationwide solution. Cooperative improvement of the earthen channels by the farmers with the government providing the design and materials for concrete control structures had a benefit:cost ratio of at least 3 to 1 and was eagerly accepted by the farmers. Subsequent studies indicated that a good and regular cleaning and repair program would save almost as much water and provide higher benefits with much lower government input.

12. DESCRIPTORS (920)

Watercourses
Research
Participation
Tubewells
Pakistan
Water management
Farmers

13. PROJECT NUMBER (150)

931048900

14. CONTRACT NO.(140)	15. CONTRACT TYPE (140)
AID/ta-C-1411	Res.

16. TYPE OF DOCUMENT (160)

AID 590-7 (10-79)

PK
631.7
K32a

PN-AAJ-011

ORTIUM FOR
NATIONAL
DEVELOPMENT

Colorado State University
University of Arizona
University of California at Davis
and at Riverside
Utah State University

New Mexico State University
Oregon State University
Texas Tech University
University of Idaho
Washington State University

WATERCOURSE IMPROVEMENT RESEARCH IN PAKISTAN

By W. Doral Kemper,
Wayne Clyma,
Gaylord V. Skogerboe
and Thomas J. Trout

Water Management Research Project
Colorado State University
Fort Collins, Colorado

January 1980

WATER MANAGEMENT
TECHNICAL REPORT NO. 56

WATERCOURSE IMPROVEMENT RESEARCH IN PAKISTAN

WATER MANAGEMENT TECHNICAL REPORT 56

Prepared under support of
United States Agency for International Development
Contract AID/ta-C-1411.
All reported opinions, conclusions or recommendations are those of the authors and not those of the funding agency or the United States Government.

Prepared by
W. Doral Kemper
Wayne Clyma
Gaylord V. Skogerboe
Thomas J. Trout

Water Management Research Project
Engineering Research Center
Colorado State University
Fort Collins, Colorado

January 1980

WATER MANAGEMENT TECHNICAL REPORTS*

Consortium for International Development

Colorado State University

No.	Title	Author	No. of Pages	Cost
1	Bibliography with Annotations on Water Diversion, Conveyance, and Application for Irrigation and Drainage, CER69-70KM3, Sept. 1969	K. Mahmood A. G. Mercer E. V. Richardson	165	$3.00
**2	Organization of Water Management for Agricultural Production in West Pakistan (a Progress Report) ID70-71-1, May 1970	P.O. Foss J.A. Straayer R. Dildine A. Dwyer R. Schmidt	148	$3.00
3	Dye Dilution Method of Discharge Measurement, CER70-71 WSL-EVR47, January 1971	W.S. Liang E.V. Richardson	36	$3.00
4	Not available			
**5	The Economics of Water Use, An Inquiry into the Economic Behavior of Farmers in West Pakistan, MISC-D-70-71DW44, March 1971	Debebe Worku	176	$3.00
**6	Pakistan Government and Administration: A Comprehensive Bibliography, ID70-71GNJ17, March 1971	Garth N. Jones	114	$3.00
**7	The Effect of Data Limitations on the Application of Systems Analysis to Water Resources Planning in Developing Countries, CED70-71LG35, May 1971	Luis E. Garcia-Martinez	225	$3.00
**8	The Problem of Under-Irrigation in West Pakistan: Research Studies and Needs, ID70-71GNJ-RLA19	G.N. Jones R.L. Anderson	53	$3.00
9	Check-Drop-Energy Dissipator Structures in Irrigation Systems, AER70-71, GVS-VTS-WRW4, May 1971	G.V. Skogerboe V.T. Somoray W.R. Walker	180	$3.00
**10	Maximum Water Delivery in Irrigation	J.H. Duke, Jr.	213	$3.00

*Reports are available from Publications Office, Engineering Research Center, Colorado State University, Fort Collins, CO 80523. Price: as indicated until supply is exhausted; subsequent Xerox copies obtainable at 10 cents per page. Postage and handling: $1.00 in the U.S.; $2.00 to foreign addresses.

**Supply exhausted.

No.	Title	Author	No. of Pages	Cost
11	Flow in Sand-Bed Channels	K. Mahmood	292	$3.00
**12	Effect of Settlement on Flume Ratings	T.Y. Wu	98	$3.00
**13	The Problem of Water Scheduling in West Pakistan: Research Studies and Needs, ID71-72GNJ8, November 1971	G.N. Jones	39	$3.00
**14	Monastery Model of Development: Towards a Strategy of Large Scale Planned Change, ID71-72GNJ9, November 1971	G.N. Jones	77	$3.00
**15	Width Constrictions in Open Channels	J.W. Hugh Barrett	106	$3.00
**16	Cutthroat Flume Discharge Relations	Ray S. Bennett	133	$3.00
**17	Culverts as Flow Measuring Devices	Va-son Boonkird	104	$3.00
18	Salt Water Coning Beneath Fresh Water Wells	Brij Mohan Sahni	168	$3.00
19	Installation and Field Use of Cutthroat Flumes for Water Management	G.V. Skogerboe Ray S. Bennett Wynn R. Walker	131	$3.00
20	Steady and Unsteady Flow of Fresh Water in Saline Aquifers	D.B. McWhorter	51	$3.00
21	Dualism in Mexican Agricultural Development: Irrigation Development and the Puebla Project	H.H. Biggs	28	$3.00
22	The Puebla Project: Progress and Problems	H.H. Biggs	23	$3.00
**23	Pakistan Government and Administration: A Comprehensive Bibliography, Volume No. 3	G.N. Jones	259	$3.00
24	Index for the Eight Near East-South Asia Irrigation Practices Seminars	W.L. Neal C. Stockmyer	58	$3.00
25	A Bibliography and Literature Review of Groundwater Geology Studies in the Indus River Basin	Alfred J. Tamburi	33	$3.00

No.	Title	Author	No. of Pages	Cost
26	Planning Sediment Distribution in Surface Irrigation Systems	Khalid Mahmood	67	$3.00
27	Practical Skimming Well Design	F.A. Zuberi D.B. McWhorter	61	$3.00
28	Physical, Salinity, and Fertility Analyses of Selected Pakistan Soils	W.T. Franklin W.R. Schmehl	29	$3.00
29	Program for Computing Equilibrium Solution Composition in $CaCO_3$ and $CaSO_4$ Systems from Irrigation Water Compositions	Dhanpat Rai W.T. Franklin	42	$3.00
30	Conjunctive Use of Indus Basin Waters--Pakistan: A General Summary of Ph.D. Dissertation	M.T. Chaudhry	37	$3.00
**31	Informational Sources on Water Management for Agricultural Production in Pakistan with Special Reference to Institutional and Human Factors, Volume I Volume II	G.N. Jones A.R. Rizwani M.B. Malik R.F. Schmidt	170 251	$3.00
32	Crop Water Use and Yield Models with Limited Soil Water	H.M. Neghassi	119	$3.00
33	Design of Irrigation Drop Structures	Soon-kuk Kwun	123	$3.00
34	A Study of Village Organizational Factors Affecting Water Management Decision Making in Pakistan	A.H. Mirza	129	$3.00
35	Village Organizational Factors Affecting Water Management Decision-Making Among Punjabi Farmers	A.H. Mirza D.M. Freeman J.B. Eckert	62	$3.00
36	Organizational Alternatives to Improve On-Farm Water Management in Pakistan	George E. Radosevich	252	$3.00
37	Improving Farm Water Management in Pakistan	Gilbert L. Corey Wayne Clyma	32	$3.00
38	The Importance of Farm Water Management in Pakistan	Wayne Clyma Gilbert L. Corey	28	$3.00

No.	Title	Author	No. of Pages	Cost
39	Irrigation Practices and Application Efficiencies in Pakistan	Wayne Clyma Arshad Ali M.M. Ashraf	36	$3.00
40	Calibration and Application of Jensen-Haise Evapotranspiration Equation	Wayne Clyma M.R. Chaudhry	16	$3.00
41	Plant Uptake of Water From a Water Table	Chaudhry Nuruddin Ahmad	88	$3.00
42	Physical and Socio-Economic Dynamics of a Watercourse in Pakistan's Punjab: System Constraints and Farmers' Responses	M.K. Lowdermilk Wayne Clyma Alan C. Early	106	$3.00
43	Water Management Alternatives for Pakistan: A Tentative Appraisal	Jerry Eckert Niel Dimick Wayne Clyma	61	$3.00
44	Water User Organizations for Improving Irrigated Agriculture: Applicability to Pakistan	George E. Radosevich	34	$3.00
45	Watercourse Improvement in Pakistan: Pilot Study in Cooperation with Farmers at Tubewell 56L	CSU Field Party and Mona Reclamation Experimental Staff (Pakistan)	93	$3.00
46	Planning and Implementing Procedures for Contracting Agricultural-Related Research Programs in Low Income Nations	Max K. Lowdermilk Wayne Clyma W. Doral Kemper Sidney A. Bowers	46	$3.00
47	A Research-Development Process for Improvement of On-Farm Water Management	Wayne Clyma Max K. Lowdermilk Gilbert L. Corey	58	$3.00
48	Farm Irrigation Constraints and Farmers' Responses: Comprehensive Field Survey in Pakistan			
	Volume I - Summary	Max K. Lowdermilk Alan C. Early David M. Freeman		$5.00
	Volume II - Purpose of the Study, Its Significance, and Description of the Irrigation System	Max K. Lowdermilk David M. Freeman Alan C. Early		
	Volume III - Consequences of the Present Farm Water Management System	Alan C. Early Max K. Lowdermilk David M. Freeman		

No.	Title	Author	No. of Pages	Cost
Volume IV - Major Constraints Confronting Farmers Explaining the Consequent Low Crop Yields		Max K. Lowdermilk David M. Freeman Alan C. Early	250	
Volume V - Farmer Responses to Major Constraints: Viable Options Under Present Conditions		David M. Freeman Max K. Lowdermilk Alan C. Early	52	
Volume VI - Appendices		David M. Freeman Max K. Lowdermilk Alan C. Early	319	
Volumes II through VI are sold as a set only				$20.00
49A	Evaluation and Improvement of Irrigation Systems	Gideon Peri G.V. Skogerboe		$3.00
49B	Evaluation and Improvement of Basin Irrigation	Gideon Peri G.V. Skogerboe Donald Norum	179	$6.00
49C	Evaluation and Improvement of Border Irrigation	Gideon Peri Donald Norum G.V. Skogerboe	105	$3.00
50	Factors Affecting Losses from Indus Basin Irrigation Channels	Thomas J. Trout	201	$6.00
Special Technical Reports				
	Institutional Framework for Improved On-Farm Water Management in Pakistan	Water Management Research Project Staff	88	$3.00
	Recalibration of Small Cutthroat Flumes for Use in Pakistan	G.V. Skogerboe Abbas A. Fiuzat Thomas J. Trout Richard L. Aust	82	$3.00
51	Farm Water Management in Upland Areas of Baluchistan	W.D. Kemper Mazher-ul-Haq Ahmad Saeed	77	$3.00
52	Operational Irrigation Evaluation of Pakistan Watercourse Conveyance Systems	Thomas J. Trout S.A. Bowers	104	$3.00
53	Irrigation and Honor: Cultural Impediments to the Improvement of Local Level Water Management in Punjab, Pakistan	Douglas J. Merrey	61	$3.00

No.	Title	Author	No. of Pages	Cost
54	Constraints on Small Farmers in the Precision Land Leveling Program in the Pakistani Punjab	Raymond Z.H. Renfro	123	$6.00
55	Organizational Problems and Their Consequences on Improved Water-courses in Punjab	Ashfaq Hussain Mirza and Douglas J. Merrey	186	$6.00
56	Watercourse Improvement Research in Pakistan	W. Doral Kemper Wayne Clyma Gaylord V. Skogerboe Thomas J. Trout	107	$6.00
57	Optimization of Lengths of Alternative Watercourse Improvement Programs	John O. Reuss	49	$3.00
58	Watercourse Improvement Manual	Thomas J. Trout W. Doral Kemper	258	$9.00

WATERCOURSE IMPROVEMENT RESEARCH IN PAKISTAN

Abstract

This research program was funded by USAID, organized by CSU and sent out to identify good investments for developing countries in water management. Loss of almost half of the water from watercourses was identified as a primary waste of irrigation water which is a limiting factor in crop production in Pakistan. Physical causes of the loss were identified as high porosity of upper portions of the banks due to burrowing activities of rodents, insects and worms, thin fragile banks near junctions due to borrowing of soil for weekly construction of dams, and rising levels of water in the watercourse due to vegetative growth and sedimentation.

Difficulty in organizing farmers to accomplish regular cleaning and repair was identified as an underlying sociologic cause of the loss.

Experimental masonry and concrete watercourses were built by the government and given to the farmers. They were too expensive and required too much cement to provide a nationwide solution. Moreover, farmers did not appreciate and maintain them because they had no investment therein. Other lined watercourses on which the government paid for materials and the farmers provided labor were better appreciated and maintained, but took longer to build and still required large amounts of cement and were too costly for a national program. Cooperative improvement of the earthen channels by the farmers with the government providing the materials and design for concrete control structures at the junctions was developed as a program which had a benefit:cost ratio of at least 3 to 1 and was eagerly accepted by the farmers in a study which involved a series of case histories. Host government and USAID officials were invited to inspect these field studies and consult with participant farmers. They were sufficiently impressed with the product, the farmers' enthusiasm and the data on costs and benefits, that they asked the CSU team and their host country cooperators to assist in development of a national water management improvement program. This type of watercourse improvement became the primary component which "sold" the program and brought benefits to small as well as large farmers.

Subsequent studies indicated that a good and regular cleaning and repair program would save almost as much water and provide higher benefits with much lower government input. However, the watercourse improvement program with its concrete control structures was more eagerly accepted by the farmers.

Full benefits of the improvement program were obtained only by farmer groups who organized themselves to clean and maintain their watercourses regularly. To motivate and facilitate such organization, a well designed education program is needed which would clearly demonstrate and emphasize cause and effect relations between cleaning and repair and reduced losses. Enabling laws are needed to provide authority to elected local leaders to organize the farmers for this purpose and penalize "freeloaders" who do not do their share of the work.

The "research" involved was pragmatic, achieved its purpose, and was highly satisfying to the participants.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

LIST OF TABLES

WATERCOURSE IMPROVEMENT RESEARCH IN PAKISTAN[1]

W. Doral Kemper, Wayne Clyma, Gaylord V. Skogerboe
and Thomas J. Trout[2]

I. Introduction

The purpose of this report is to outline steps followed and the lessons learned in a USAID-funded water management research program. This program was designed to provide the basis for a development program which would help improve water management and crop production. The total program actually had three components designed to increase: (1) the portion of the water from the canals and tubewells which is delivered to the farmer's field, (2) the portion of the water reaching the fields which is made available to the crop root zone, and (3) the efficiency with which the water which is left in this root zone is utilized in the production of crops. This report will be restricted to the first of these three components because it has been the most completely developed to date. The latter two components are considered even more important and are being emphasized at this time.

Pakistan, with its population nearing 75 million and an annual rate of population increase of nearly 3.5 percent, is close to self sufficiency in food production. However, it has to import food in years when crop production is average or below. Such imports are a heavy burden on the limited foreign exchange because Pakistan must also buy a good part of its manufactured goods and petroleum products. Consequently, Pakistan must look to its agricultural potential to provide at least 3.5 percent more food each year to keep its people fed. Increased food production is also needed to provide food for other nations and thereby gain the foreign exchange necessary to increase Pakistan's manufacturing and productive abilities.

Pakistan has one of the world's largest contiguous irrigation systems with water from the mighty Indus and its tributaries serving approximately 33 million acres of land In most of this area, irrigation is a prerequisite of crop production. The original irrigation system was built to

1/Prepared under support of the United States Agency for International Development, Contract AID/ta-C-1411, Department of State, Washington, D.C.
2/Professor, Associate Professor, Professor and Research Assistant Professor, Department of Agricultural and Chemical Engineering, Colorado State University, Fort Collins, Colorado, respectively.

command more land area than could be irrigated by the water diverted from the Indus River and its tributaries. During any particular season the farmers are normally irrigating and cropping about 60 percent of their land area. Consequently, additional water delivered to the farmer's field can generally be utilized and translated into more acres cropped and harvested.

II. Identification of the Problem

After observation of Pakistan's irrigation system in 1970-71, Dr. G. L. Corey, Chief of the CSU Water Management Field Party, and Mian Moh'd Ashraf, the Director of the Mona Reclamation Experimental Project, decided that improved water management could bring about appreciable benefits to Pakistan. They wrote a proposal to the U. S. Agency for International Development to fund a study which would improve the water management including the water delivery efficiency. It seemed obvious to them that the watercourses were losing a great deal of the water as they carried it from the canals to the farmer's field.

However, these observations were not in line with the thinking of the large portion of the people dealing with water management in Pakistan. The programmers and water system modelers had been led to believe that the losses from the watercourses were only about 10 percent. The Irrigation Department officials and their field workers also seemed to be accepting this 10 percent loss figure. Several reports by internationally recognized consulting firms during the years from 1966 through 1971 also accepted this loss figure.

Tracing this 10 percent loss concept back to the original data on which it was based, the CSU Field Party and their cooperators found (e.g., see Ashraf, et al., 1977) that the data was based on 11 observations of water loss on carefully selected sections of watercourses in which the "outlets were avoided or carefully sealed with mud to prevent leakage." These sections were selected to be straight with no junctions or widened places where buffalo or other activity had weakened banks (Huntington Technical Services, 1965). These sections were filled with water and the rates of recession were determined by knowing the surface area of the watercourse and its rate of recession. The volume of water being lost in the section could be calculated with a high degree of accuracy. A short term expert who didn't have time to take measurements himself concluded that the losses measured in those sections was the best available estimate of the rate of water loss from watercourses during their operation. Succeeding flights of experts did not have either the funding, the time, or the inclination to go out and take more measurements and consequently they simply accepted the loss figure of the first expert in drawing up their models of how water was used and misused in the great Indus hydrological system.

These data on which this assumption was built were taken in the lower Indus Basin and in about 1972 the Irrigation Department of the Punjab decided to determine rates of loss in the Punjab. They adopted almost identical criteria for selection of their watercourses to be tested, used the same methods and obtained loss estimates similar to those obtained in the lower Indus Basin. Their data were used by many people to reinforce the conclusion that only about 10 percent of the water was being lost from the watercourses.

Consequently, when Corey and Ashraf included the delivery channels as one of the major components of the irrigation system which they hoped to improve, they were depending on their visual observations and experience to support their investment in watercourse improvement. Their visual estimates were definitely not supported by the data available at that time or by most of the professionals engaged in water management in Pakistan.

In 1972, the CSU Field Party and their cooperators began taking flow measurements in watercourses while the farmers were using those watercourses. Director Ashraf of the Mona Reclamation Experimental Project was informed that the first watercourse on which measurements had been taken was losing over half of its water before it reached the fields. Even though Director Ashraf had helped prepare the proposal to evaluate the losses he questioned whether the losses were this great and consequently accepted an invitation to the field to participate in and check on the measurements. Project directors are extremely busy persons in Pakistan and consequently it is a tribute to Ashraf's sense of values that he joined the CSU adviser on the next trip to the field to measure the flow losses. Again, the measurements showed the losses to be around 50 percent. The CSU adviser was not sure that Ashraf was convinced until a few weeks later when he heard Ashraf describe these losses to his superior and speak of the losses that "we have measured". The CSU adviser had taken two major steps that are essential for an expatriate adviser to get the problem solving process off to a good start. These were:

1. To physically identify the problem; and

2. To involve responsible host country officials in the identification so that they can verify the findings and take part of the credit for them.

A question still unanswered was whether the high rates of loss measured on these watercourses at the Mona Reclamation Experimental Project were characteristic of the losses occurring on watercourses throughout Pakistan. It became apparent that a large number of measurements would have to be taken to obtain a reliable estimate of the losses throughout the country. The cross-sectional grid and current meter method used initially was time consuming and it was realized that flumes installed near the head of the watercourse and near where the water was entering the fields would be a simpler method of measurement. Consequently, a CSU engineer, who had recently developed and calibrated a simplified new flume, was contacted and asked for construction details and calibrations for these flumes. The Field Party gave these construction details to a local manufacturer and placed orders for several of these "Cutthroat flumes". The first products of the local manufacturer were not acceptable, but insistence on standards and technical guidance by the CSU Field Party and the developer, and a cooperative attitude on the part of the manufacturer resulted in a product which could measure the flow rates in the watercourses in Pakistan with reasonable accuracy at a reasonable cost.

The results of these measurements of water losses from watercourses (e.g. Clyma, et al., 1975) were sent back to the CSU campus office and were reported by the Project Coordinator in a seminar. Several Pakistani students who had been working in Pakistan disagreed with these numbers and said they could not possibly be correct because it was common knowledge in Pakistan that losses from watercourses averaged about 10 percent. When asked for their supporting evidence of the 10 percent loss figure, they brought copies of the reports of three highly respected international consulting agencies, all of which quoted the 10 percent loss figure. The campus based Project Coordinator, alarmed at this apparent array of contradicting evidence, sent a letter to the field cautioning the field party member to check his methods and make sure he was not sampling particularly poor watercourses before he spread the word too widely. The field party member was not pleased with this apparent questioning of his equipment, technical ability or good judgment. He and his Field Party Chief let the campus based Project Coordinator know that they considered his attitude less than supportive of this aspect of the field work.

The Project Coordinator had by this time decided to take a tour as the new Field Party Chief. When he arrived in Pakistan, he found immediate opportunities to go to the field and to work with one of the host country cooperators who had been measuring the losses from watercourses using the Cutthroat flumes. These measurements showed about the same rates of loss as the CSU field party had previously reported.

However, the continuing arguments against the higher loss figure by the majority of the Pakistan Government personnel working with water management and the argument that ponding and recession measurements could be made more precisely than flume measurements of loss led the new Party Chief and his Pakistani cooperators to use the ponding and recession method to make extensive measurements of loss on several watercourses. They found (e.g. Akram and Kemper, 1978) that the rate of loss was extremely dependent upon the height of the water in the watercourse. In fact, it increased by a factor of approximately two for each 0.2 ft increase in elevation of water in a watercourse when no overtopping was occurring as indicated in Figure 1. Consequently, it was extremely important when comparing loss measurements using the flume method and the ponding and recession method, that the rate of loss using the ponding and recession method be determined when the water level was at the same level as occurred while the farmer was using the watercourse.

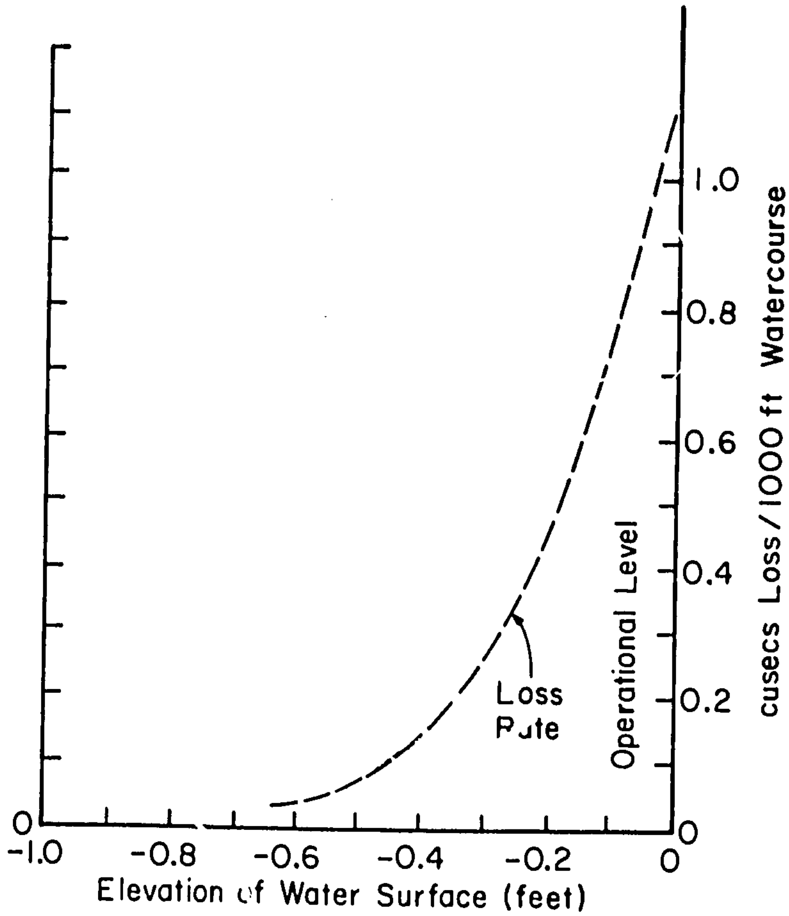


Figure 1. Loss rate as a function of surface elevation.

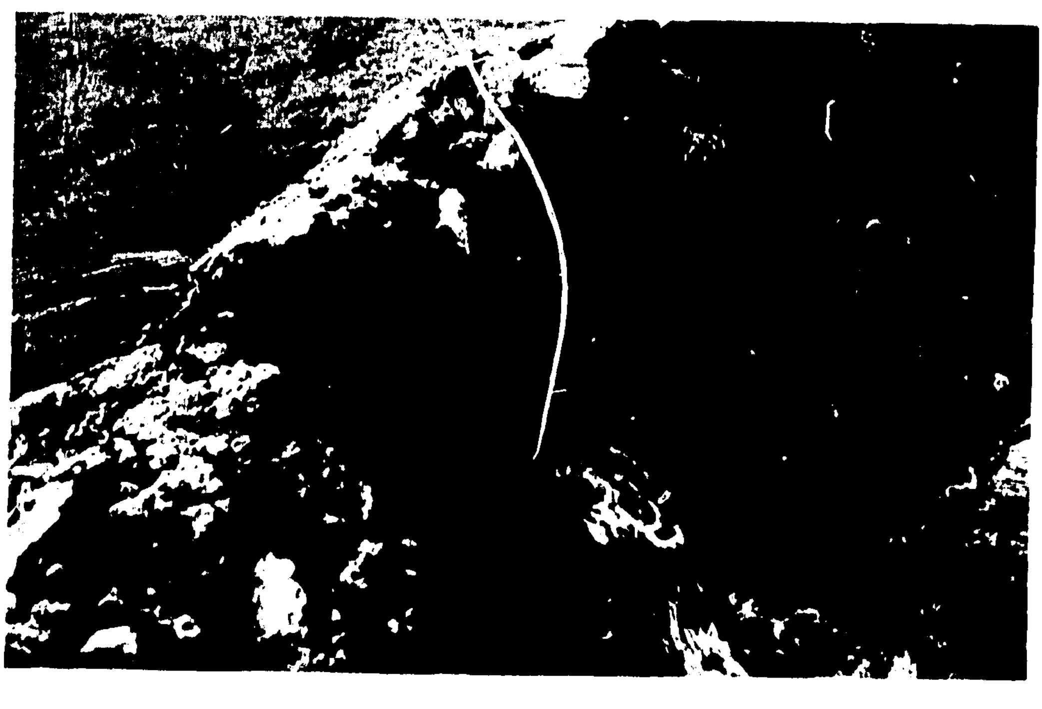


Figure 2. Leakage through trimmed bank near a junction.

These data pointed out limitations of both methods and reasons why the previously taken sets of measurements using the ponding and recession method probably did not agree with the flume measurements which the CSU Field Party had been taking. In the data taken by the Punjab Irrigation Department, for instance, using the ponding method, they had generally started with the water level near the operational level but then had measured the rate of loss while the water level receded approximately 6 inches and then averaged the rate of loss over this complete time period. According to the data of the type shown in Figure 1 this would result in an underestimate of the rate of real operational water loss by a factor of about 2.

On the other hand, it is also true that placement of a flume in a watercourse results in raising the water level upstream from that flume and increases the rate of water loss in the area immediately upstream from the flume. This results in more water loss taking place than would have been the case if the flume had not been in the watercourse. If the distance upstream to which the water level is raised is several hundred feet and the length of the watercourse section being measured is only one or two thousand feet, this effect of the flume on the level of the water can increase the rate of loss to 1.2 to 1.5 times the rate of loss that would have occurred if the flume had not been in the watercourse. If the distance between the two flumes is 5000 or 6000 feet and the head loss at the lower flume is kept down to about 1/10 of a foot, the measured rate of loss on these sections will be about 1.03 to 1.06 times the actual operational loss (Trout, 1979).

Observations indicated that a large portion of the losses on some watercourses occurred at or near the junctions where two branches of a watercourse come together. Regular borrowing of soil from the banks and near the banks has left the banks extremely narrow and leaky as indicated in Figure 2. Using the ponding method on a few such junction sections and the intermediate straight sections it was found that almost half of the water lost from some watercourses was lost in the vicinity of these junctions. Avoiding junctions, or carefully plastering closed the holes on the "carefully selected sections" studied in the Lower Indus Report and Punjab Irrigation Department Studies, plus inclusion of time periods when water levels were considerably below operational in obtaining loss data resulted in their loss measurements being only about 1/4 those from operating watercourses. Flume measurements of loss probably average about 1.1 times the average operational losses. These considerations rationalize differences between the 90 percent delivery efficiency assumed previously and the 50 percent delivery efficiency measured with flumes. The real operational delivery efficiency averages about 55 percent (Ashraf, et al., 1977).

A series of short publications reporting these findings was mimeographed and circulated among the Pakistan Government

Agencies and the USAID Mission personnel in Pakistan. The Punjab Irrigation Department steadfastly argued against these findings. Part of their refusal to admit high losses in Punjabi watercourses may have been tied to the fact that other Provinces sharing the Indus water were using these high water loss data found in the Punjab as an argument that watercourse improvement in the Punjab could increase supplies to Punjabi farmers' fields and therefore more of the Indus water should be allowed to go to the other Provinces. (The situation was somewhat similar to that between Colorado and California in the fifties.) However, there were still many persons who clung to the traditional 10 percent loss concept, and many of these persons insisted that the measurements taken on over 20 watercourses by the CSU personnel had, by chance or design, been taken on watercourses which had more leakage than the average. To allay these arguments and to establish whether there were differences in water losses in different parts of the country, a survey was designed which covered 41 watercourses in the Punjab and Sind provinces (this survey included measurements of delivery and application efficiencies, degrees of unlevelness of the crop lands and determinations of farmer's concepts and attitudes affecting their water management). These survey measurements (Lowdermilk, et al., 1978) indicated that about 47 percent of the water leaving the canals was not reaching the average field in Pakistan and that there were no significant differences between the efficiency of delivery of watercourses in Punjab and Sind Provinces.

There was some question as to whether loss measurements taken at one time during the week are representative of true operational losses. For instance, the watercourse loss measurements were generally taken when the water flowing out of the canal and the water flowing into the fields were at relatively steady state conditions. Such steady state measurements obviously do not account for those transient conditions when watercourses are being filled, or watercourses are being drained after the watercourse has been turned out of the branch. To remedy this deficiency, Sidney Bowers, Tom Trout and their cooperators conducted a series of studies in which the amount of water coming out of the canal was monitored for a complete week during which time the water was rotated through all of the branches of the sarkari khals. They also measured the amount of water that was being delivered to all of the fields during this period of time. An example of the type of data which they obtained is given in Figure 3. In general, they found (Trout and Bowers, 1979) that about seven percent of the water that enters a watercourse is used in filling the dead storage and wetting the dry banks of watercourses. These losses approximately compensated for the overestimate caused by flumes raising the water level and consequently, steady state measurements discussed by Clyma, et al. (1975) and Lowdermilk, et al. (1978) are reasonably good estimates of the overall water losses on a watercourse.

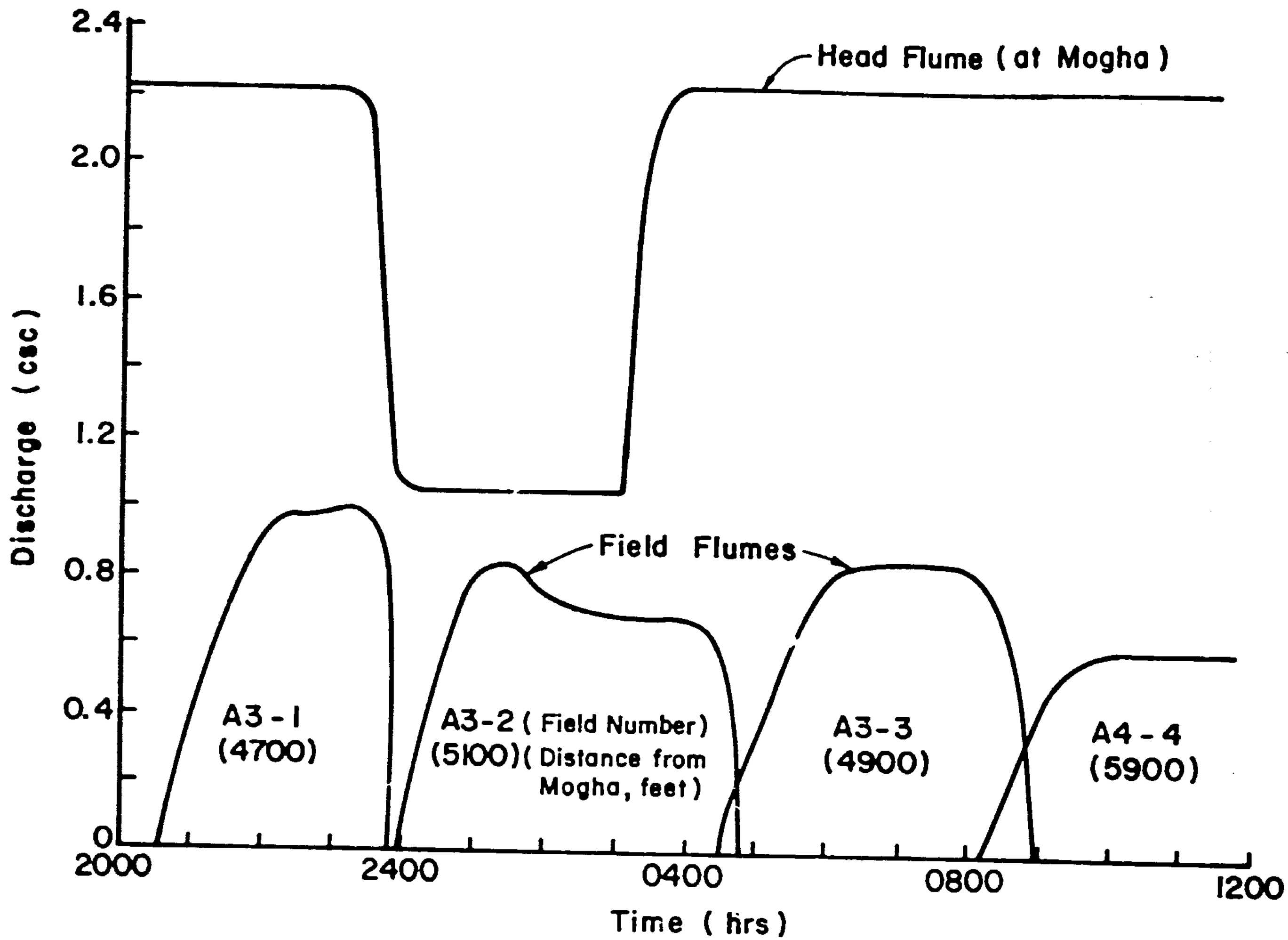


Figure 3. Water deliveries and losses during operation of watercourses (Trout et al., 1978).

There was still some question on the part of WAPDA and some World Bank officials as to whether the water losses measured at one point in time were sufficiently represenative of the losses throughout the year. Consequently, it was proposed by the World Bank that WAPDA conduct a study of these and other water management and crop production related parameters throughout an entire year. This survey was visualized and was in the planning stages about the time when the USAID-funded WAPDA survey conducted by Early and Lowdermilk and their team as initiated. Early and Lowdermilk were consulted concerning its content, methodology, and implementation. An agreement was reached whereby the personnel trained by Lowdermilk and Early were hired for the World Bank-WAPDA survey when the USAID-WAPDA survey was completed.

These trained and experienced personnel who had nearly one year's practical field experience with the survey procedures were able to take leadership positions in the WAPDA-World Bank survey. However, to maintain other commitments it was necessary for the CSU team to forego active participation with the WAPDA-World Bank survey. Harza International acted as consultants to WAPDA in the latter survey. The CSU team felt that their disassociation from this survey would be a wise move in terms of convincing water management experts that water loss measurements did not have to be taken by CSU personnel and their immediate cooperators to be high.[3] Despite the fact that there were some persons in Pakistan who refused to change their opinions, a real water management problem had been identified--only about 55 percent of the water leaving the canal was reaching the farms. The reasons for these high losses were also, to some extent, identified. They included:

1. A lack of organization among the 30 to 150 farmers who shared common watercourses and had some difficulty in getting together to do the work or raise the finances which would have provided them with the structures needed to avoid the junction deteriorations and subsequent losses.

2. The official attitude of Irrigation Department officials that "the losses were only about 10 percent and were therefore inconsequential" extended down through the ranks of the Irrigation Department to the farmers and diminished the incentive for putting forth effort to clean, maintain and improve their watercourses.

3/The Irrigation Department still argued against the results of this survey and conducted a spirited campaign to discredit the accuracy of the Cutthroat flume used as the basic measurement tool in this study. This prompted a careful recalibration of the flumes of the size used in this study (Skogerboe, et al., 1979). The basic calibration curves for these flumes were found to be within ± 2% of the original curves.

This latter attitude indicates one of the most dangerous tendencies which tend to keep a country from developing to fulfill its potential. When we delude ourselves into believing that we have obtained our objectives and have a high degree of efficiency, we destroy our initiative and often the initiative of succeeding generations that might otherwise have brought about improvement.

The major lesson learned was never depend entirely on the measurements taken by others even if those measurements appear to have been concurred in by some of the world's outstanding authorities. Short term "experts" should be given time to take at least a few measurements of the critical parameters affecting their conclusions, or their conclusions may include inaccuracies which prevent the country from recognizing its potential for improvement.

III. Development and Evaluation of Solutions

A. Build for the Future--Concrete and Masonry

Observations of the poor state of repair of the farmers' watercourses (e.g. Mirza, et al., 1976) showed that most of these farmer groups had not been able to work out a satisfactory cleaning and maintenance program and raised the issue as to whether farmers would or could maintain earthen watercourses in reasonable shape. Moreover the history of irrigation development in many of the developed countries generally shows a series of improvements leading to concrete and masonry delivery systems. The question arose as to whether we should not take advantage of our knowledge of this development process, skip some of the intermediate steps and go directly to concrete and masonry watercourses.

Consequently, a series of concrete and masonry test sections were constructed on the watercourses serving Tubewell 78 and Tubewell 122 in the Mona Project area. These watercourses have the cross-sectional designs indicated in Figure 4 and were constructed at the costs indicated in Table 1. Water losses from unimproved watercourses and the improved watercourses are indicated in Table 2. During construction and in the initial evaluations of the quality of the concrete and masonry work, it became apparent that constant supervision of the contractors, by a person who had a strong interest in seeing a quality job done was necessary to assure that the prescribed amounts of cement were incorporated in the mortar and concrete, and that the mixing was complete. The loss data listed in Table 2 shows that, although lined channels can have very low loss rates, several of the lined test sections lost water nearly at the rate of unlined channels, probably because of poor construction techniques.

The farmers were inconvenienced to some extent by the construction of the watercourses which put their main channels out of operation for periods ranging from 1 to 12 months. They generally constructed a temporary bypass watercourse which carried water to their farms. However, these bypass watercourses were generally smaller than needed to carry the water, had practically zero freeboard in many places and were often at elevations lower than needed to supply the surrounding fields. However, most of the farmers endured the inconvenience and were reasonably satisfied with their new watercourses.

The major point of dissatisfaction centered around the outlet and check structures which were constructed of steel as shown in Figure 5. When these steel check structures are properly manufactured and properly installed they work very well. However, in many cases the control structures had not been manufactured to the required specifications or had been

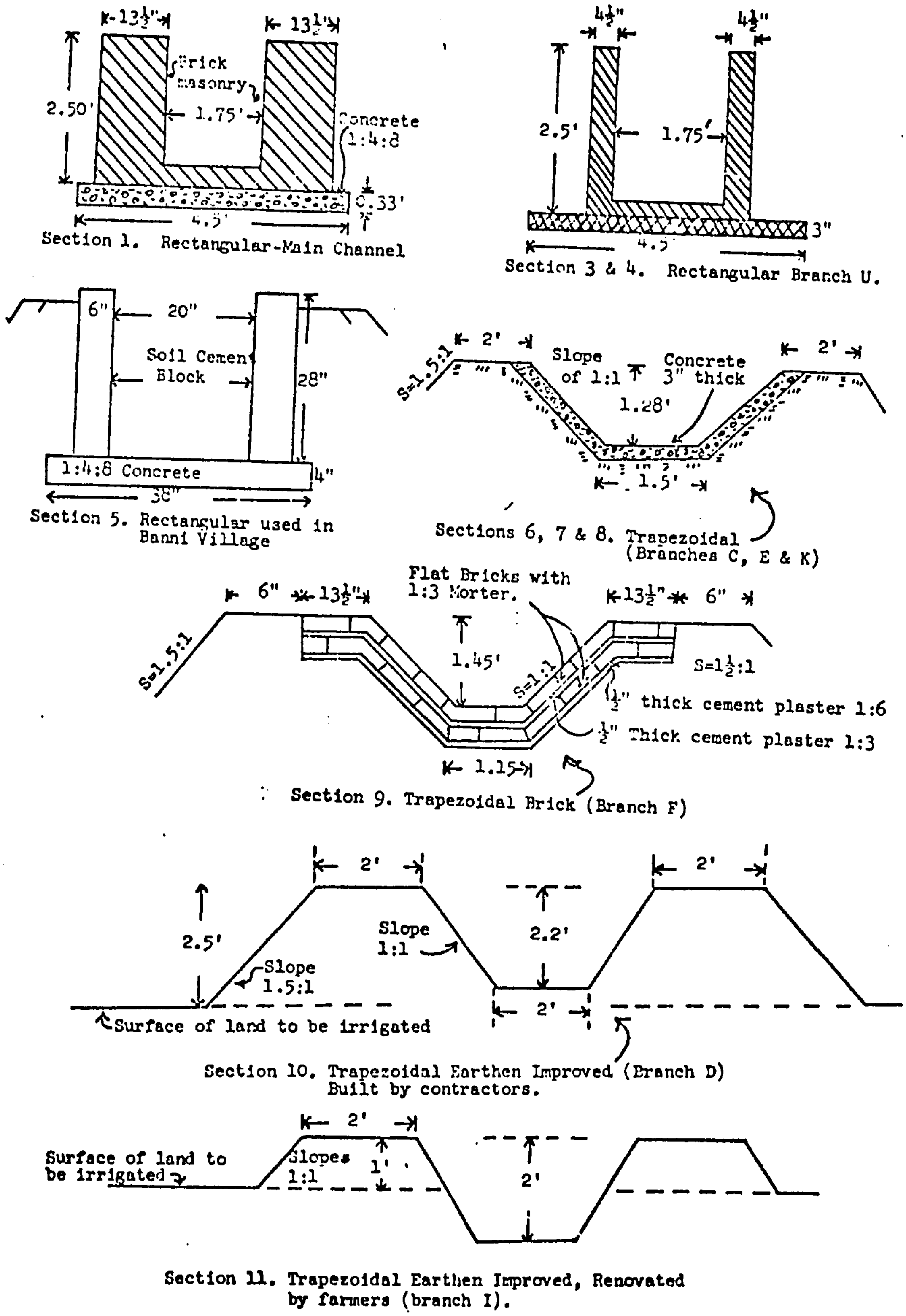


Figure 4. Cross-sectional designs of watercourses tested at Tubewell 78.

Table 1. Cost and Details of Construction of Watercourse Serving TW No. MN-78.

Section	Description	Length	Cost Rs/1000 ft	Type/Design
1.	Main Channel	5280	41,480	Rectangular Section. Brick Masonry. 13-1/2" Thick wall.
2.	Main Channel Watercourse	2240	55,810	Rectangular Section. Brick Masonry. 9" Thick Wall.
3.	Branch "U"	1000	26,930	Rectangular Section. Brick Masonry. 4-1/2" Thick wall.
4.	Branch "U"	1000	26,930	Rectangular Section. Brick Masonry. 4-1/2" Thick wall. 3" Thick C.C. 1:4:8 Foundation.
5.	Banni Village	220	18,000 20,000 (Plastered)	Rectangular Section. Base of 1:4:8 concrete. Walls of 6x4x12" soil cement block.
6.	Branch "C"	769	35,150	Trapezoidal Section. Cement Concrete 3" Thick (1:3:6).
7.	Branch "E"	642	36,240	Trapezoidal Section. Cement Concrete 3" Thick (1:2:4).
8.	Branch "K"	908	36,260	Trapezoidal Section. Cement Concrete 3" Thick (1:4:8).
9.	Branch "F"	3248	55,210	Trapezoidal Section with 2 Brick Layers.
10.	Branch "D"	4600	10,920	Trapezoidal Section. Earthen Improved. Built by Contractors.
11.	Branch "I"	2200	2,000	Trapezoidal Earthen Improved. Built by Farmers.

*Cost includes construction of check structures and outlets.

Table 2. Rates of Loss from Pakka Sections at Tubewell 78 Watercourse

Description of Section	Repli-cation	Rates of Loss in cusecs per 1000 ft. Before plastering or repair	After plastering or repair	Cost of repair or plastering (Rs./1000 ft.)
Rectangular section, plastered brick walls 12-1/2" thick (main channel)	1	0.009		
	2	0.007		
Trapezoidal section, concrete 1:3:6 walls 3" thick (Branch "C")	1	0.040		1290
	2	0.059		
Trapezoidal Section, concrete 1:2:4 walls 3" thick (Branch "E")	1	0.414	.014	1290
	2	0.354		
Trapezoidal Section, Concrete 1:4:8, walls 3" thick (Branch "K")	1	0.341	.022	1290
	2	0.750		
Trapezoidal Section, Double thick brick walls (Branch "F")	1	0.103	.012	1290
	2	0.197		
Rectangular section, plastered brick walls 9" thick (Lower main channel)	1	0.348	.005**	218
	2	0.595	.013	
Rectangular section, plastered brick walls 4-1/2" thick (Branch "U")	1	0.057	.038**	50
	2	0.104		
Rectangular section, plastered soil cement block walls 6" thick ("I")	1	0.004		
	2*	0.002		
Rectangular section, unplastered soil cement block 6" thick ("I")	1	0.082	0.048+	160
	2	0.087	0.036+	
Rectangular section, plastered brick walls 9" thick (Branch "F")	1	0.30	0.04***	286
Rectangular section brick walls 9" thick (Branch "F")	1	0.56	0.01	1800
	2	0.96		

* Plaster containing Pakka Kaum (Sodium silicate)

** Repair of old plastering job where poorly mixed plaster (sand) had eroded away.

*** Rain, beginning when this plaster repair had not had time to set caused some washout of the plaster at the repair points.

+ "Pointing", or filling of obvious holes in joints between blocks 6 months after construction.

Figure 5. Steel check gate on a watercourse.

installed in such a manner that the plates did not slide freely in the frame. This tendency increased as the frame and the plates developed the normal rust and scale. The plates became almost impossible to move in several cases. With their vital water supply at stake, and no apparent alternative available that could be initiated before their irrigation turn was over, the farmers resorted to beating on the plates and their handles with various instruments to try and move them up and down. The normal result was further and sudden deterioration of the structure to the point where it was completely inoperative.

Another disturbing attitude was a lack of responsibility on the part of the farmers for the watercourses once they were installed. The farmers were told, after the watercourses were constructed, that the watercourses were now theirs and it was their responsibility to take care of them. However, they did not accept this responsibility. For instance, on one occasion, when the farmers had accidentally closed all the gates leading out of the watercourse, it overflowed causing considerable erosion of the soil away from the concrete wall. The next morning the farmers approached the project personnel, pointed out the damage that had occurred and "demanded" that "the government come and repair the government's watercourse". This attitude toward the test sections indicated that the farmers did not fully appreciate the investment which had been made for them and that they did not have a feeling of responsibility for its maintenance. Having been given so much, they expected this generosity on the part of the government to continue and expand.

Other masonry watercourses were started with the Integrated Rural Development Program of the Punjab Agriculture Department at Maraka and Lar. These watercourse improvement projects were planned on the basis that the government would supply the material and the farmers would provide the labor. In both cases, the farmers were, at one point in time, enthusiastic and reasonably united in the objectives of the improvement projects. In both cases, transfer of the trained government personnel to other assignments, and a failure to get technical personnel and materials to the site while the farmers' interest was high, resulted in a delay of the program. Bickering developed among the participants as to who was responsible for the lack of progress, and in both cases the program as originally planned was not completed. A primary lesson learned from these projects was that once the farmers are united in their enthusiasm for the program, it is highly important that the technical personnel be maintained on the project and that they be on site each day to assure continuity of the program. It is also essential that the government organization involved have purchasing procedures which allow the arrival of the essential materials at the construction site in a manner such as to facilitate the continuous smooth operation of the construction project.

The concrete or masonry lining of a whole watercourse requires such a long period of time (several months) that personnel transfers and incidents which cause bickering and refusal of the farmers to work together are more likely to occur than in shorter term projects.

B. A Low Cost Alternative - Earthen Improvements

The high rates of water loss from existing watercourses, plus the rapid change in loss rates with changing flow depths, indicate that watercourse channel banks are 4 to 20 times as permeable as the soil in the surrounding fields. Cursory observations indicate that the excessive seepage rates are probably the result of leakage into rat, worm, insect, and old root holes which honeycomb most channel banks.

The high seepage rates and their probable cause indicated that loss rates could be significantly reduced by eliminating the cause of the excess seepage in the earthen channels. Consequently test sections were constructed which involved destroying the old watercourse banks and reconstructing them from the same soils, a procedure which eliminated most of the large holes in the banks.

Ponding measurements on the reconstructed sections indicated that loss rates could be significantly reduced, sometimes to less than 30 percent of the previous rate, especially in sections where the previous loss rates were high. Careful bank reconstruction utilizing clean (no vegetation) soils and good compaction resulted in loss rates which were as low as the average loss rates measured in some of the lined channels (Figure 6). Although the initial potential for water savings from earthen improvements was dramatic, the effective life of such improvements could only be determined in long term studies.

If the excessive losses are a result of highly porous banks, the question was posed whether the compaction of the cores in the banks of existing watercourses would reduce the losses. Consequently (Kemper and Akram, 1975), a packer was built with a head 5 by 10 cm in cross section and weighing about 7 kilograms. With water in the watercourse at approximately the operational level, the sod and soil were removed from the inside half of the bank as indicated in Figure 7, using shovels (kassies) down to near the surface level of the water. The compactor was then used to pound the soil downward in approximately the center of the bank, displacing the soil from the trench 5 to 10 cm wide and ranging from 7 to 20 cm deep. The greater depth was achieved when the soil had the greatest porosity. After the soil had been displaced, the trench was filled with moist soil. This fill soil was compacted again and this process was repeated until the volume from which the soil had been displaced was filled with a

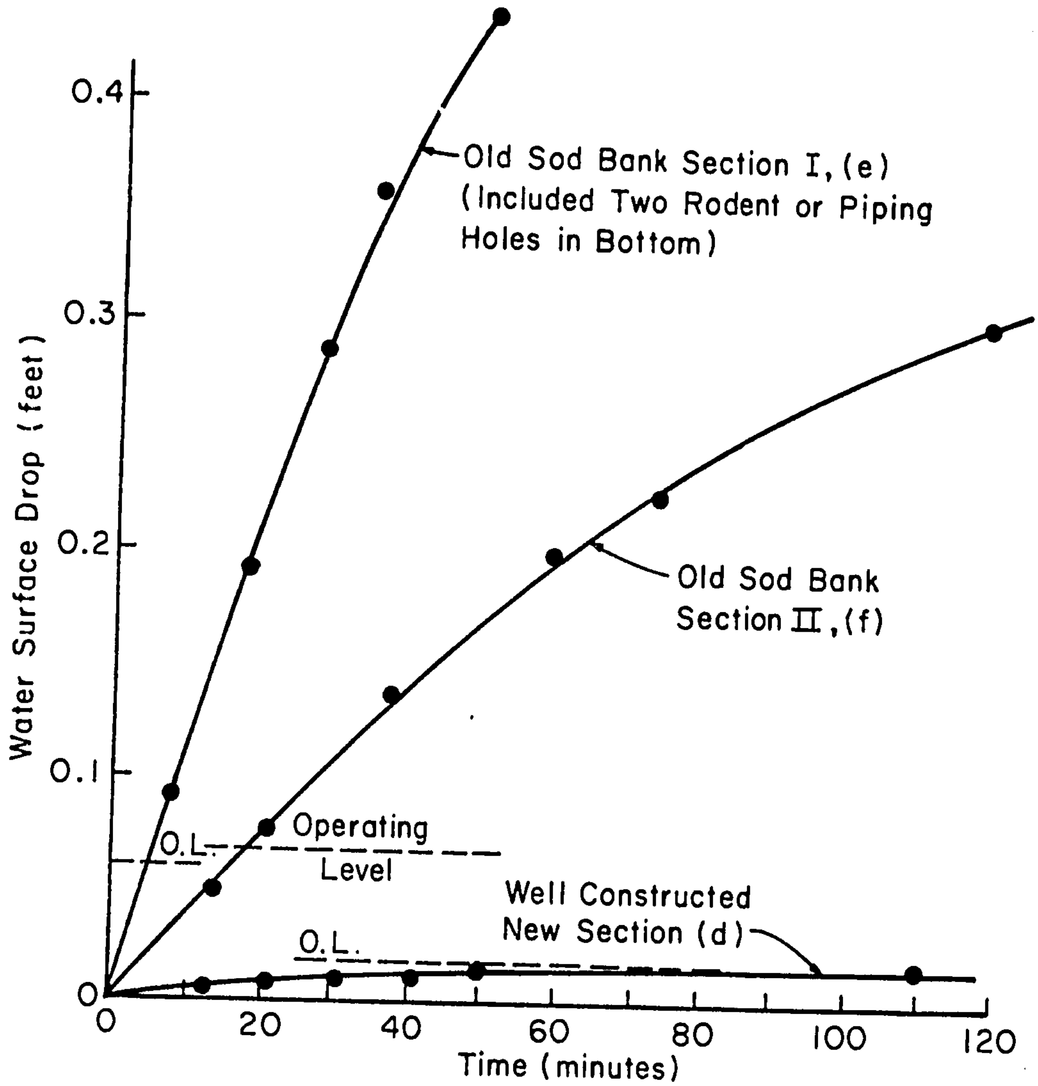


Figure 6. Water loss from ponded channel sections on and below the Rauf plots of the Mohlenwal Khurd watercourse (loam soil).

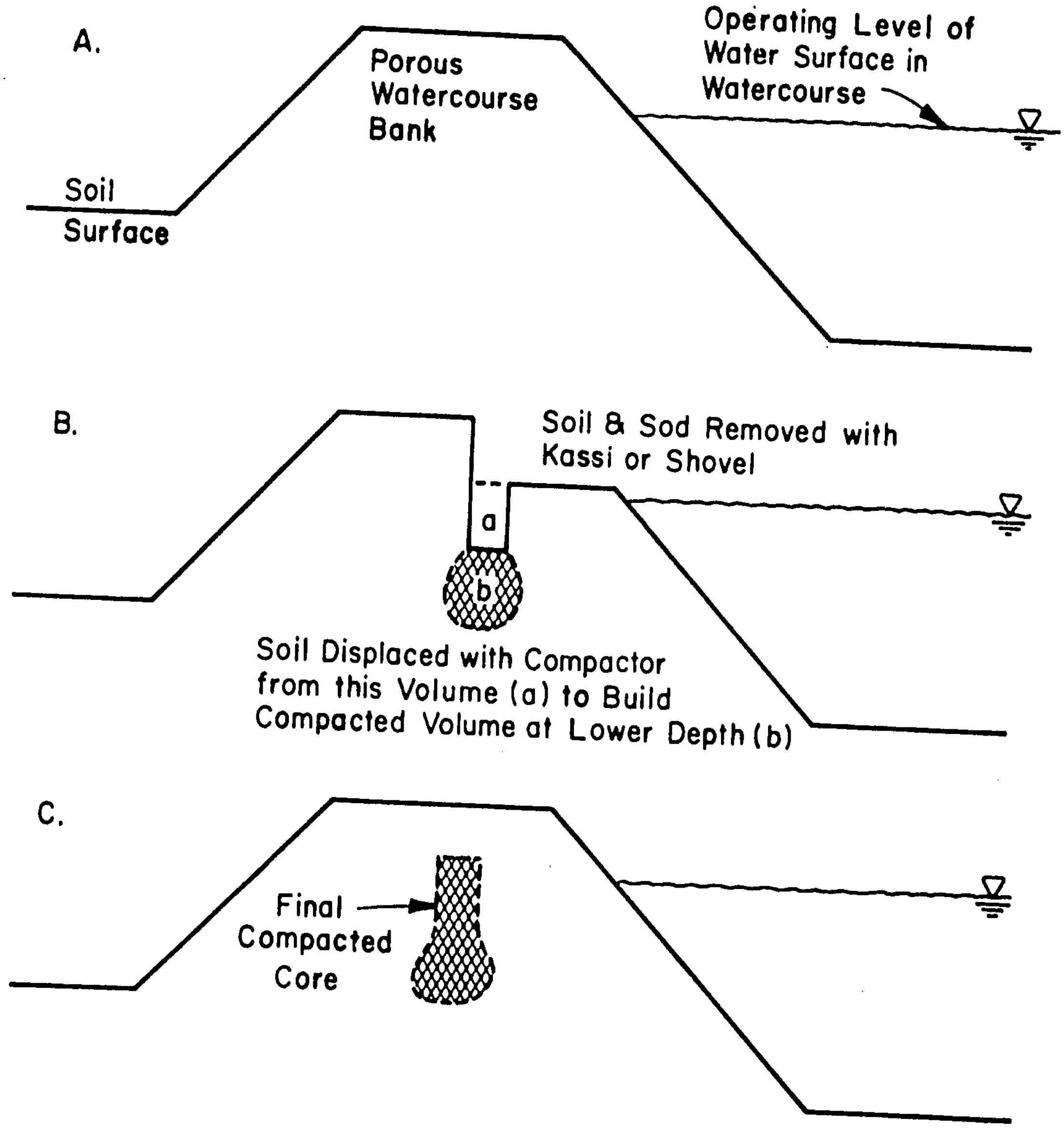


Figure 7. Steps used in forming compacted cores in watercourse banks.

compacted soil core. The soil and sod excavated from the top of the bank was then replaced as indicated in Figure 7 and pressed into place by foot. The results of this operation was a compacted core of soil about 8 cm wide and 15 to 30 cm deep with the top of this soil being an inch or so above the operating level of the water. One man could easily install six meters of this type of core in a watercourse bank per hour, or in other words, could install this type of core in both banks of a watercourse to improve three meters per hour.

Loss rates in the core compacted sections were variable, but tended to be significantly lower than the pre-core loss rates. Further measurements to better determine the potential water savings from core compaction and the life of such loss reductions should be carried out. Since core compaction requires only about 1/6 to 1/4 the labor required to reconstruct watercourse banks, it appears to be an efficient method of reducing losses in existing channels which have sufficient width and freeboard. Unfortunately, most watercourse banks in Pakistan are too low or thin for core compaction without at least some reconstruction work, especially in junction areas.

C. Low Cost Masonry Improvements - Masonry and Concrete Cores

Most of the water loss from watercourses was found to be through the upper portions of the bank (Kemper, et al., 1975). The bottoms of the watercourses leak very little because the sediment from the watercourse settle out on these surfaces and seal them against loss; and because these zones are saturated or extremely wet much of the time, and consequently, insects and rodents do not choose to live and burrow as extensively in these sections.

The compacted soil core study indicated that blocking the pores in the upper portions of the bank could succeed in stopping much of the water loss. However, long term measurement of the loss from these watercourses with the compacted earthen cores showed that eventually the burrowing activity of rodents creates holes even through these compacted soil cores.

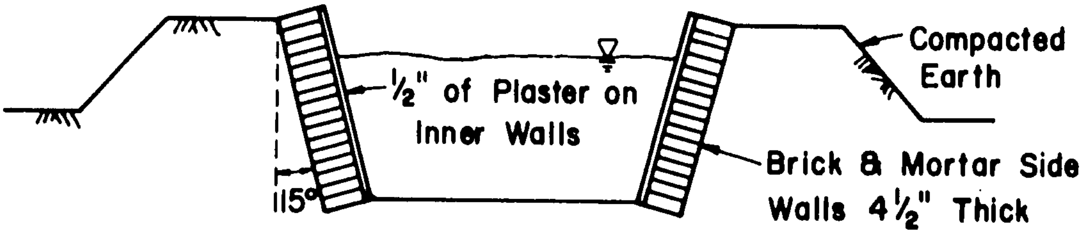
Consequently, a series of masonry, concrete, and sheet plastic cores was designed and installed (by Moh'd Akram in the Mona project area) with intent that the cores would be a permanent barrier against the hole boring activities of the rodents and insects in this particular zone through which most of the loss takes place. Initial water loss measurements following installation of these cores indicates a reduction of losses similar to that measured in the earthen cored sections. Long term benefits are being evaluated.

1. Side Linings

Masonry lining involving vertical walls allows development of considerable side pressure on these walls. If there is no earth on the outside of the lined channel, when the watercourse is full of water, the pressure of the water from the inside is not balanced by an equivalent force from outside, and consequently, the walls must be strong and have a solid base or they will collapse outward. Conversely, if there is a good bank of supporting soil on the outside which supports this wall, but a small amount of leakage occurs through the wall from the watercourse, the soil on the outside of the wall becomes saturated with time if the conductivity of the wall for water is greater than that of the undisturbed surrounding soil. Since the water is often in the sections for several days, the soil can become saturated almost to the surface of the ground. When the water is suddenly taken out of the watercourse, the saturated soil on the outside of the watercourse creates a substantial pressure on the wall and often causes failure towards the inside as is indicated in Figure 8. Experience with this type of failure has led most long-term practitioners in this field to recommend that there be a very solid and thick base in the watercourses which are to have vertical walls. The common recommendation in Pakistan is a four-inch concrete base covered by three inches of brick base. They also generally recommend walls that are at least 9 inches thick and are often 13 1/2 inches thick as indicated in Figure 4. The large amounts of brick, cement and other materials involved in this type of construction make them costly (Table 1). Alternative structures of trapezoidal design were discussed above and trapezoidal watercourses with the cross sections indicated in Figure 4 are in place for testing. A strong and solid base is not necessary for these structures because the force of the water and of the masonry is always born by the supporting earth. When this earth is sufficiently compacted (and there is no frost action, which is the case in most of Pakistan) this is a stable configuration and there have been no failures for this kind of structure other than erosion of the mortar where this was not mixed properly or had inadequate amounts of cement. However, the long perimeter of this type of design, including a bottom on the watercourse and often a few layers of brick on the top of the bank also consumes a large amount of material and construction time, so that these watercourses were not appreciably less costly than those with the vertical walls.

On the basis of the findings that very little water was lost through the bottoms of watercourses, and desiring to minimize the amount of materials used in lining a watercourse, designs indicated in Figure 9 were developed and installed in test sections at the Phularwan Research farm in the Mona

Figure 8. Masonry walls 4.5" thick which have collapsed due to soil and water pressure.



A. Cross section diagram.

B. Bullock drawn packer used to compact pad

C. Excavating the channel in the compacted pad.

D. Laying the bricks.

E. Finished, plastered walls containing water in the watercourse 3 days after filling.

Figure 9. Side linings to reduce water losses and costs thereof, from watercourses.

Reclamation Experimental Project (MREP) area. These "side linings" eliminate the base lining and depend on their angle (about 15° from vertical) to prevent the inward collapse discussed above. Having the walls at 15° from vertical rather than 45° from vertical makes the walls stronger against, and less vulnerable to, vertical impacts such as buffalo stepping on them. A comparison of the material and cost estimates for these side linings indicated that they can be built for 30-60 percent of the cost of designs such as those indicated in Figure 4 for complete lining. Initial loss measurements for one of these watercourses indicates that over 80 percent of the loss is eliminated by these side linings when they are properly plastered. However, the soil supporting the banks must be compacted carefully to properly support these angled masonry walls or failure can result.

D. Structures to Control and Measure the Water and Prevent Long-Term Deterioration of the Watercourse

1. Structures and Outlets

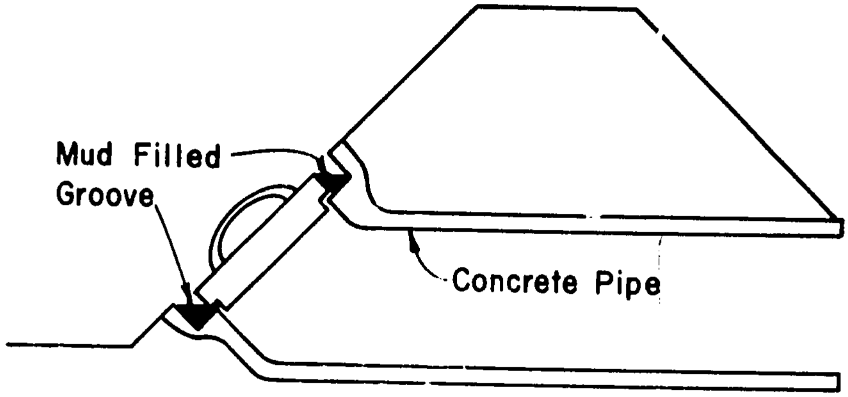
As discussed above, as much as half of the water loss in some watercourses occur at, or in the vicinity of, the junctions in the watercourse. Part of this loss is through the loose, uncompacted bunds (earthen checks) which are freshly built in an effort to halt the flow of water in one direction while it is supposed to be used in the other direction. In many cases, the farmer has to change the direction of the water flow using only his kassie which is an earth moving instrument of the type shown in Figure 10, when the total flow of water may be as high as 6 cubic feet per second. If the flows are this large and the farmer is trying to change the water at a junction from a branch where it was going to lower fields to a branch where it will go to higher fields, this can be a major battle, with the farmer often using chunks of sod, sticks, or any other object which will help him block the flow of water. In this time of extreme stress, anything goes and it is not surprising that the areas around these junctions often begin to look like a battle ground (Figure 11) with deep pits and extremely thin banks near these junctions. Control structures at these junctions reduce the tremendous effort necessary by the farmers to turn their water. Perhaps even more important, they prevent this man-made deterioration of the banks of the watercourse which accompanies the weekly battle that takes place at these junctions. The following types of outlets or check structures were designed for this purpose.

2. Pipe Outlets

Pipe outlets were designed as indicated in Figure 12 to fit into the 45° angle wall that is common to watercourses which have a 1:1 side slope. The manufacturer constructs

Figure 10. Farmer digging a watercourse with a kassi.

Figure 11. After the battles to turn the water at a junction.



A. Design.

B. Installation.

Figure 12. Pipe outlet used at junctions into branch watercourses.

them by making a regular piece of concrete pipe, but placing an eliptical ring near the end of the pipe at a 22-1/2° angle as indicated in Figure 13A. This ring allows the manufacturer to pull the end section loose from the pipe while the concrete is still green and to then rotate the end section 180° and cement it back onto the rest of the pipe, thus forming a 45° angle as indicated in Figure 13B. Small pieces of wire mesh mortared onto the outside edges of these junctions as indicated in Figure 14 increased the strength of the joint, however, several of these outlets were constructed and installed successfully without such reinforcement. The main problem encountered with these outlets was the tendency for water to leak through the area under the pipe, where firm contact between the pipe and the underlying soil was difficult to obtain. Washouts under the pipe were common during the first filling of the watercourse following installation. This tendency was eliminated by two approaches. The first was to build a cutoff wall at the ditch bank as indicated in Figure 15A. The second approach was to build a small cutoff wall in the middle of the bank along the bottom edge of the pipe by digging a trench, about 50% longer than the diameter of the pipe, parallel to the bank as indicated in Figure 15B. This trench should be dug into solid earth that has been thoroughly compacted, but it only needs to be about 6 inches wide and 4-6 inches deep. The trench is then overfilled with 1:3 cement-sand mortar mix, so that when the pipe is laid in position, the mortar forms a cradle on the bottom side making good contact with the pipe and forming a cutoff wall on the bottom side of the pipe midway through the bank. A reasonable amount of care in compacting the soil on the sides and top of the pipe is sufficient to prevent water from beginning to leak along these portions of the pipe.

The latter alternative, using a trench and placing concrete in the center of the banks, was generally much less costly than the larger cutoff wall which was necessary on the face of the bank. This type of outlet was one of the least expensive when the cost of installation was included. An outlet of this type with an internal diameter of 12 inches long and a pipe section 6 feet long would cost about $12 (Rs. 120). The head losses for large flows (4 or 5 cusecs) in pipes of 1 foot diameter are significant and consequently, if there is little head available, larger pipes must be used. This not only increases the cost of manufacture at a rate more than proportional to the size of the pipes, but also increases the cost of transport and the effort involved in installation by a factor approximately proportional to the square of the diameter of the pipe. Another disadvantage of small diameter pipes is that the velocity of the water coming out of these pipes, when the flow is 4 or 5 cusecs, is sufficently fast to cause erosion at the outlet end if the banks are not protected. When this outlet goes to watercourses which are only used one day per week, sod placed on the

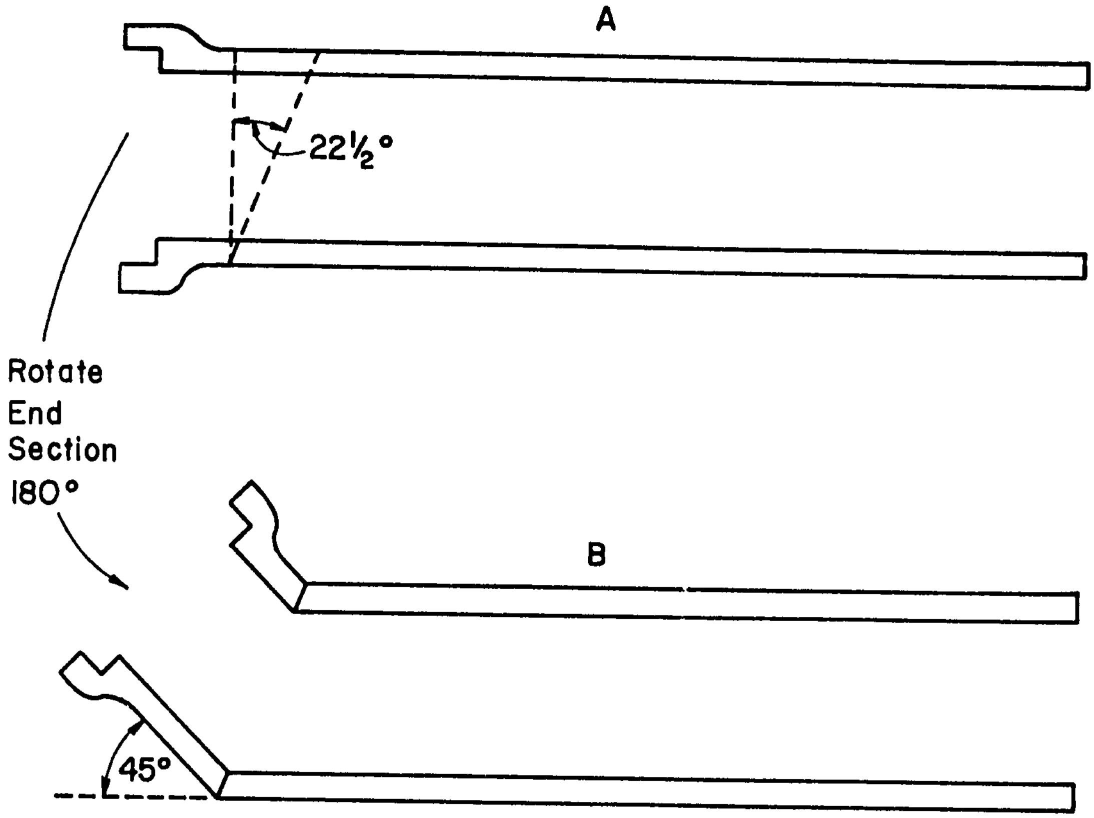


Figure 13. Steps in manufacture of 45° angle concrete pipe.

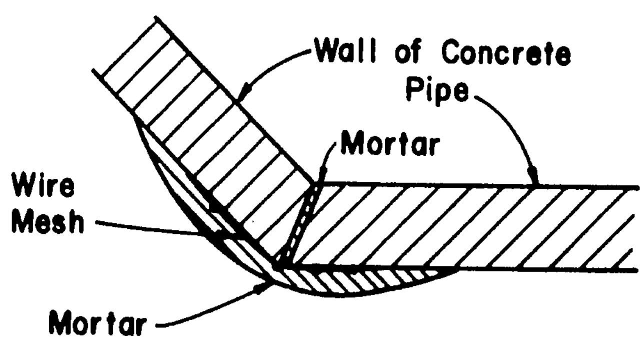


Figure 14. Detail of joining and reinforcing concrete pipe.

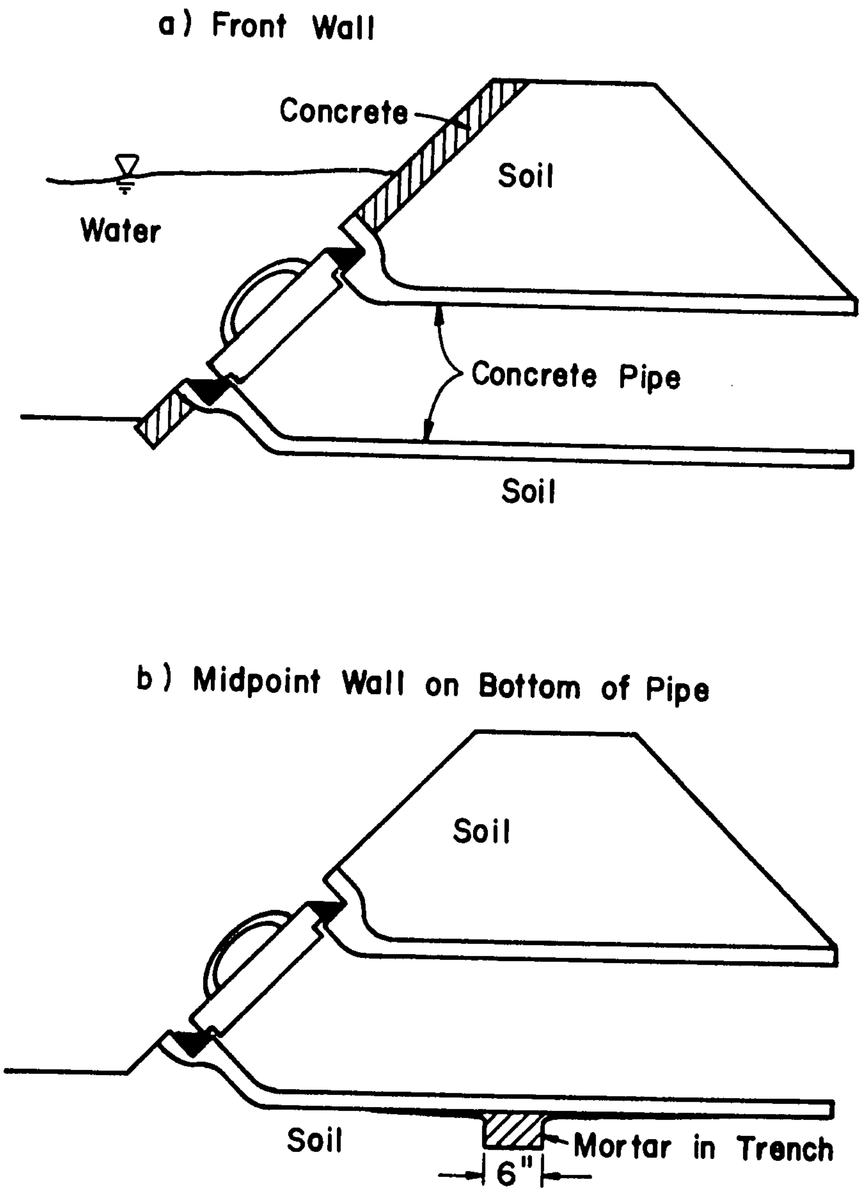


Figure 15. Cutoff walls to avoid washouts around pipe outlets.

bank near the outlet grew well and prevented such erosion. The pipe outlet has the advantage that the continuity of the top of the bank over the outlet is not broken and it can continue to serve as a foot path for human and animal traffic, which is a significant advantage in cases where this path is used as the primary access to the farmers' fields.

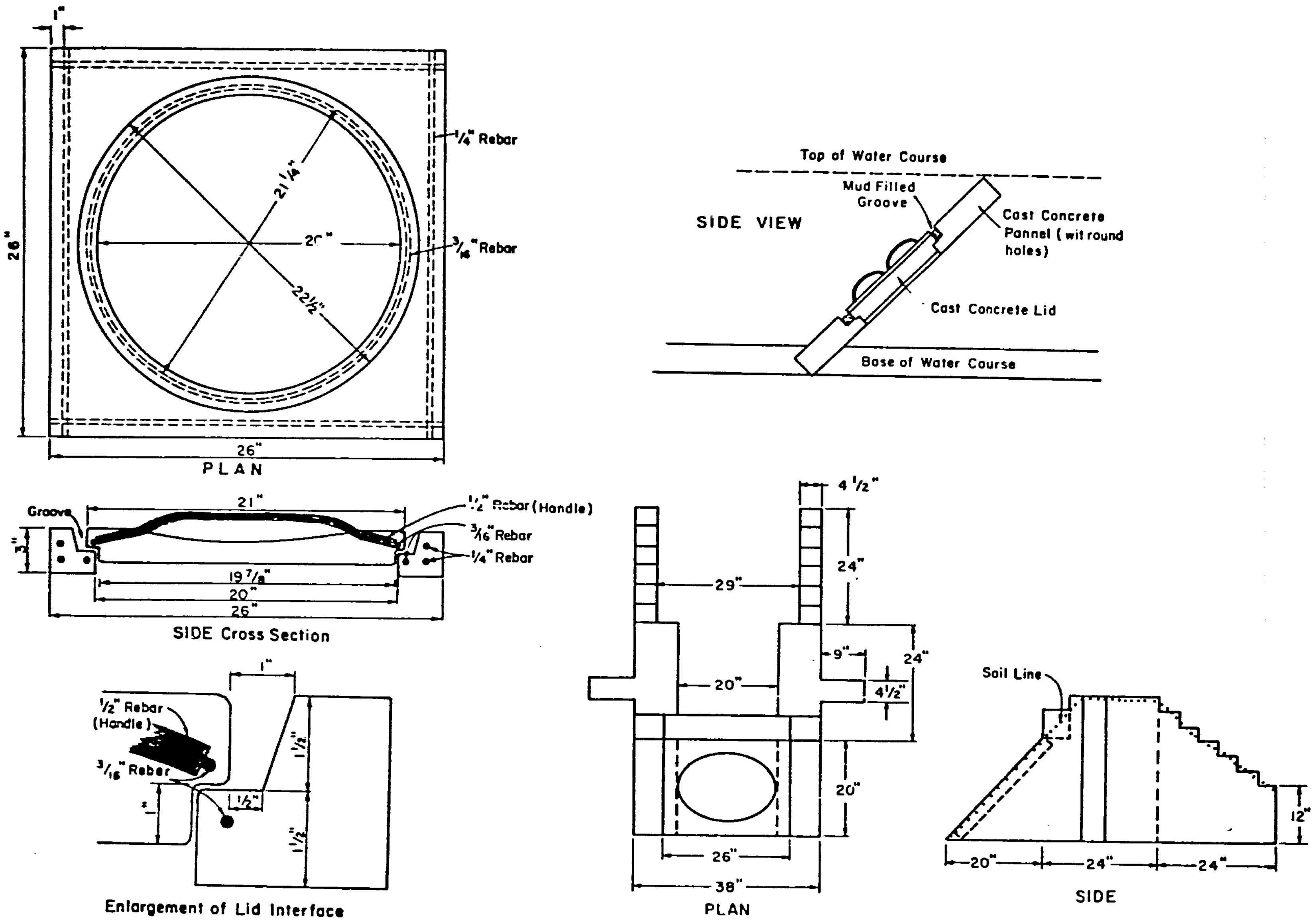
3. Precast Panel Outlets

When the flow in the watercourse is large and appreciable head loss at the outlet is undesirable, large pipes necessary to avoid the loss are difficult to install and costly. Consequently, an alternative was developed in the panel outlets indicated in Figure 16. The concrete panel with its round opening and lid were precast with the reinforcement indicated and using machined steel forms which achieved a reasonably close fit between the seal and the lid. When properly manufactured and new, these panels could reduce leakage of water through the joint between the panels and the lid to less than 1/1000 of a cusec (Trout and Akram, 1975). However, as concrete chips away during usage, some leakage develops. To help farmers prevent this leakage, a small groove was formed around the edges of the lid, which when filled with mud completely prevents the leakage.

These panels were supported at angles varying from 45 to 60° from horizontal in the watercourse by masonry structures as indicated in Figure 16B. Better sealing and closure of the lid was possible when the angles were smaller, however, these smaller angles constrict flow somewhat and result in head losses which are slightly greater than the losses which occur when the panels are at the larger angles. Improvements in the design to eliminate the sharp corners, which reduces chipping of the concrete and to obtain even better closures were developed by Tom Trout in cooperation with manufacturers in Pakistan. This improved design is shown in Figure 17.

Another method of reducing the breakage on the edges of these lids was to fit them with rubber gaskets. This worked well except in cases where the rubber gasket was stolen or destroyed by vandals. In the few locations where the rubber gaskets were left intact, it appeared that natural deterioration of the rubber would require that these gaskets be replaced every year or two depending on the material from which the gaskets were made. New gasket materials and better methods for bonding these materials to concrete are being sought.

One of the biggest improvements in the panel outlets was developed by the manufacturer. He found that he could cast the outlet panel shown in Figure 17 using a precise metal form, and then the following day, after greasing the surface, cast the lid directly into the panel. In this way he not only got a precise fit, but also could greatly streamline his



A. Details of the panels and lids.

B. Mode of installation.

Figure 16. Concrete panels with orifice and lids and supports for their installation as check structures in watercourses.

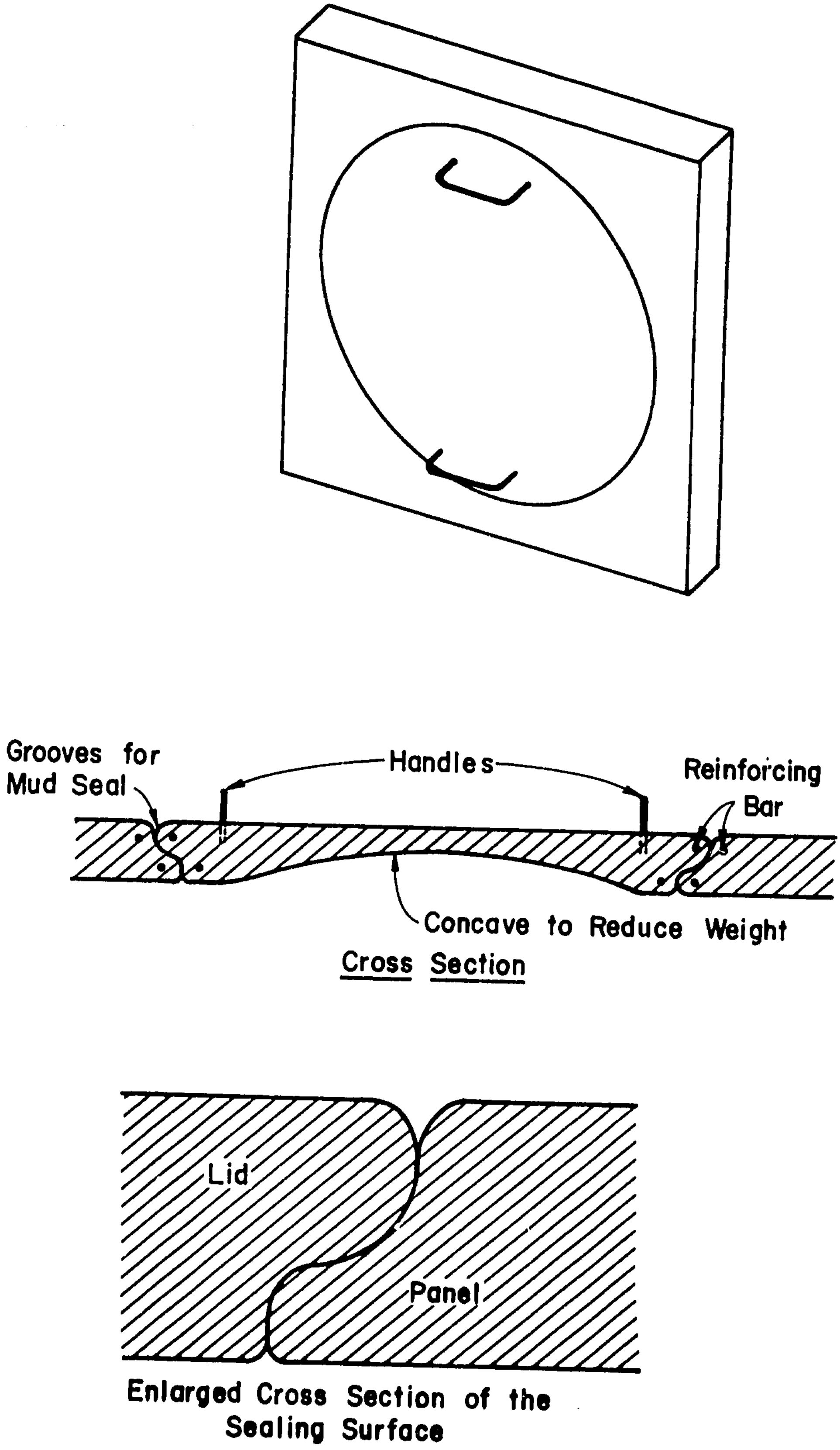


Figure 17. Improved circular panel outlet (20" and 15" diameter).

production. After curing the two pieces together in a water bath, the lid was broken loose from the panel, and then was rotated for several minutes in the panel while adding water. In this way the lids precisely fit into the panels and the sealing surface was very smooth. Water leakage through these improved outlet panels was minimal, and breakage and chipping was reduced. Further work in improving the production techniques and quality control of the concrete is being done.

A survey of 69 of the improved outlets which had been in use on 4 watercourses for from 6 to 18 months is summarized in Table 3. Ninety percent of the panels and about 2/3 of the lids were still in good condition with only 3 percent totally ruined. The average leakage rate per outlet was 0.0013 cusecs or less than 2 percent of the inflow to most watercourses were lost from the outlets. This was judged an acceptable level. Farmers were very enthusiastic about their easy-to-use and labor-saving structures, which were costing about Rs. 200 installed. As of the end of 1978, over 6000 of the circular panel turnouts had been installed.

Circular outlets could not easily be opened or closed, especially on larger watercourses, without the farmer entering the watercourse in front of the structure. To alleviate this need, a trapezoidal opening was developed, as shown in Figure 18, from which the lid could be removed from above. The outlet was constructed into a panel by the same "cast-in-place" techniques used for the circular cutlets, and thus was quite leakproof. A problem with the design was that sediment would sometimes collect on the bottom seat which would prevent the lid from closing completely. This was not a problem with the circular shape since less sediment collected on the round seat and a twist of the lid would evenly distribute the sediment around the sealing surface.

In order to eliminate the need for a skilled mason or other supplies at the field, a pre-cast concrete slab installation, shown in Figure 19, was developed. The installation also took much less time in the field than the brick masonry structure and freed up field engineers for other duties.

Preliminary studies indicate that one of the effective means for reducing loss of water from the watercourse is to lower the normal operating level of the watercourse to slightly below the soil level in the adjacent fields. Then, at the point where water is desired on the fields, the stream can be checked up to the level necessary to allow water to flow onto the field. The water can still leak out of rat holes and so forth in the short stretch near the fields where the water has been checked up to about 6 inches above field level, but in a majority of the watercourse length, the operating water level will be below the soil surface so leakage of this type will not be occurring.

Table 3. Performance of panel outlets on four selected on-farm water management watercourses.

Watercourse	Age (mo)	Lid condition				Panel condition				Structure condition				Total (cusec) (cfs)	Leakage (cfs)				Average (cfs)
		G[1]	F	P	R	G	F	P	R	G	F	P	R		0	0-.002	.002-.0035	>.0035	
Ram Diwali	12	15	3	3	2	21	0	2	0	19	4	0	0	0.02	3	3	2	2	.0020
Thikriwala	18	6	0	5	0	11	0	0	0	11	0	0	0	0.006	4	1	2	0	.0008
Bhodriwala	6	12	2	2	0	15	1	0	0	13	3	0	0	0.003	7	0	1	0	.0004
Jaranwala	6	10	1	8	0	17	0	2	0	18	1	0	0	0.019	7	0	2	3	.0016
Total No.		43	6	18	2	64	1	4	0	61	8	0	0	0.048	21	4	7	5	--
Total %		62	9	26	3	93	1	6	0	88	12	0	0	--	57	11	19	14	.0013

1/G - good
F - fair
P - poor
R - ruined

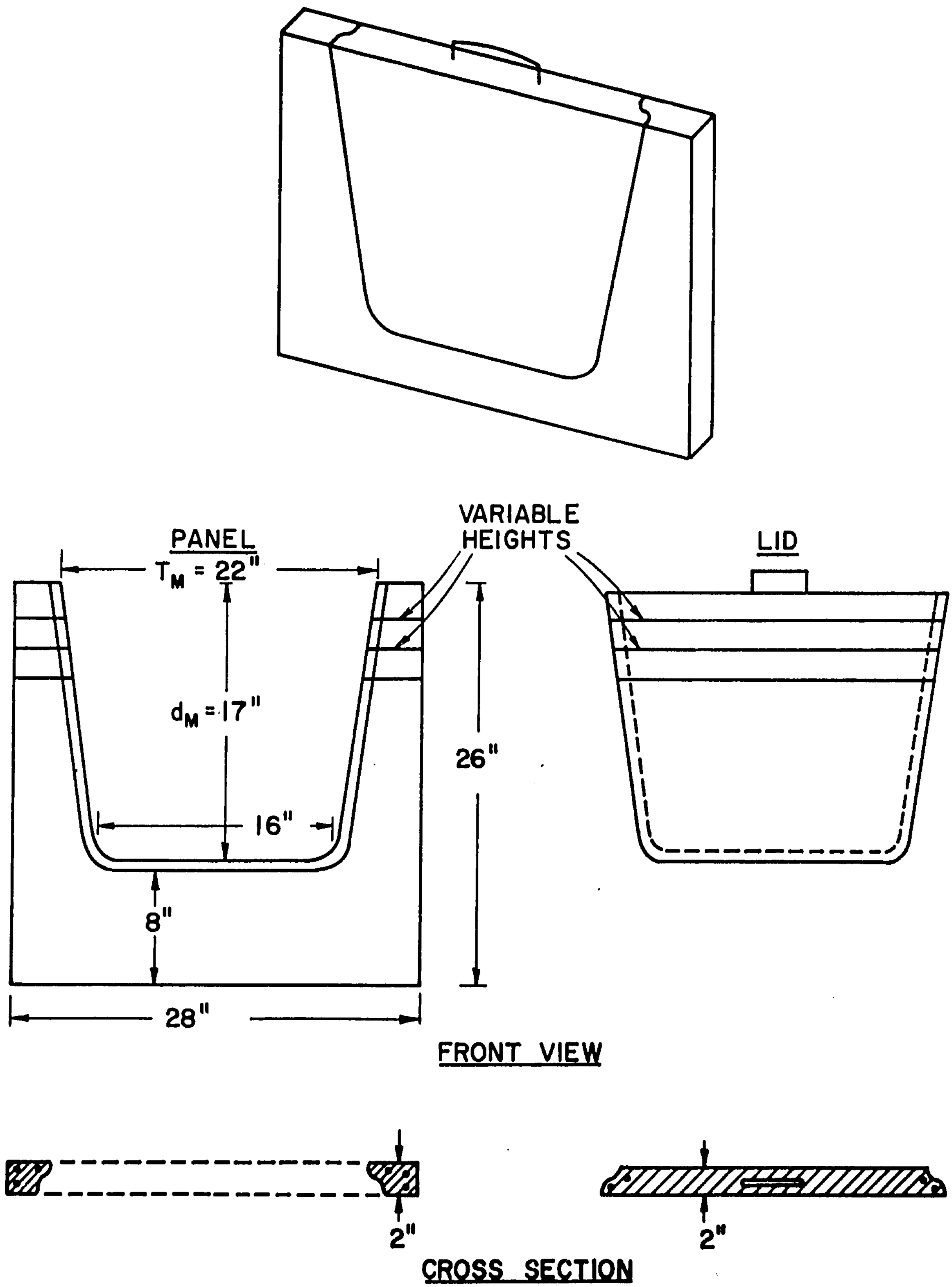


Figure 18. Trapezoidal panel outlet.

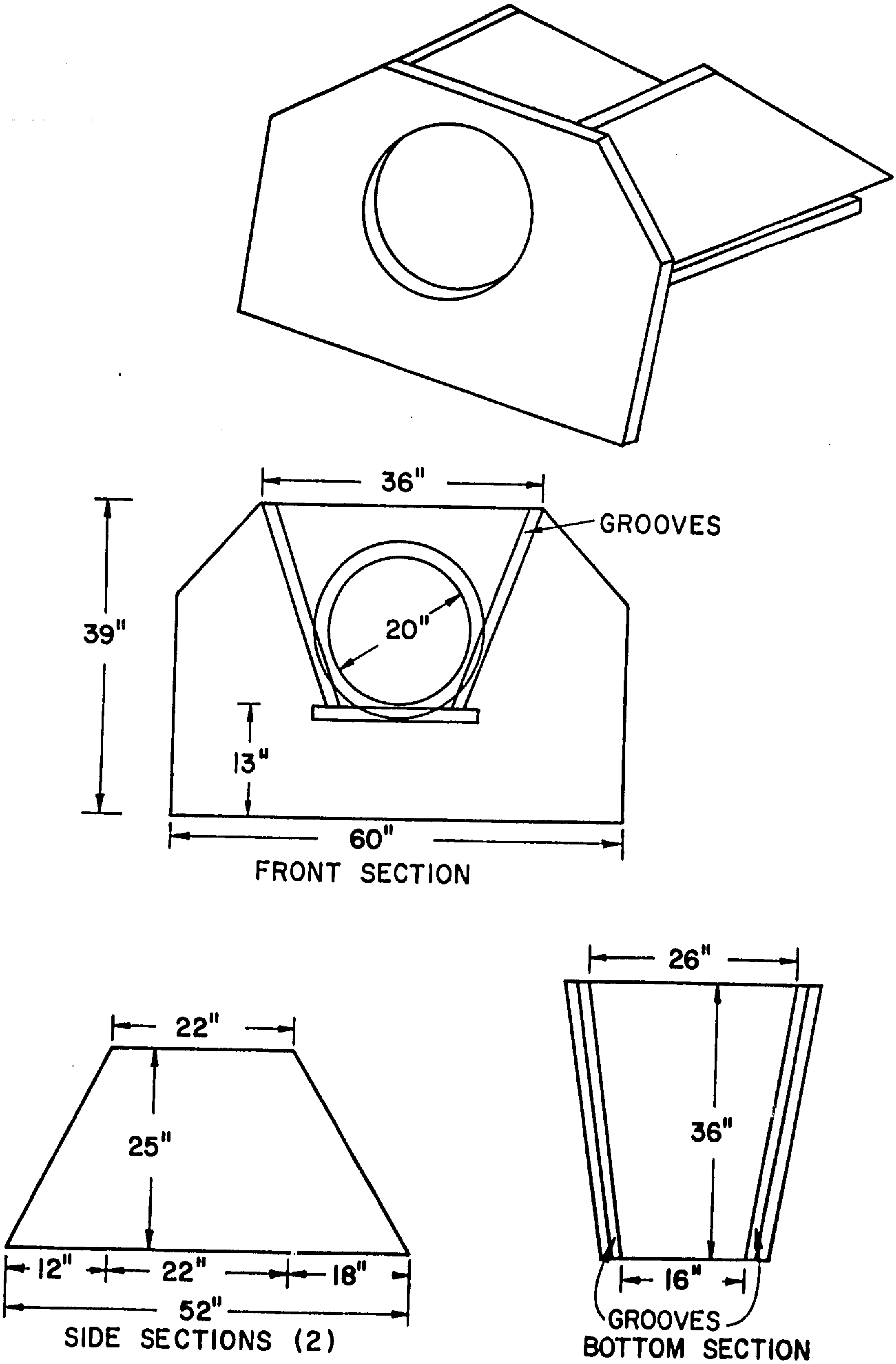


Figure 19. Precast concrete slab installation for panel outlets.

To test this concept the watercourse serving Tubewell 81L was designed so the normal operating level of the watercourse was near the adjacent soil surface level. Data taken about one year later (Ahmad and Bowers, 1978), indicate that water losses from the watercourse are about one-half of those from comparable improved watercourses where the designed operating level is about 6 inches higher than the surrounding ground surface. Field tests indicate that building a watercourse in this manner can save a substantial portion of the water loss. However, a problem which became immediately apparent was that raising the water to these higher levels placed a greater pressure on lids of the type shown in Figure 16 and made them difficult to open. For instance, raising the head of water 6 inches in the watercourse adds 68 pounds to the force necessary to pull a 20 inch diameter lid off of one of these panel nakkas. Since this has to be done in fairly deep water, the panel nakkas with lids of this type were practically unworkable. As a solution to this problem, a special type of panel and lid was built. The lid does not fit into the opening through the panel, but is a flat rectangular concrete plate which lies on top of the panel, attached to the panel with a bolt on one corner. The plate can be swivelled upward to allow the water to go through the opening. Although some of these plates broke at the corner where they were attached and special reinforcement is needed on these corners, farmers expressed delight at the relative ease of operation of this type of check structure. Leakages ranging up to 1/100 of a cusec were common. However, leakage at check structures is commonly flowing down the main watercourse and is saturating the watercourse bed, which would have to be wetted later and, therefore, is not a complete loss.

Slide check structures of the type indicated in Figure 20 were also constructed and tested on the "low operating level" watercourses. Checking the water up about 6 inches was necessary to properly deliver water to the fields. The main problems with these slide structures was that the depths of the "low operating level" watercourses were generally in excess of 2 feet, and when these slides were placed in at an angle of 45° their length often exceeded 3 feet. When the sliding panels were concrete slabs they were heavy, ranging from 80-200 pounds, and were difficult to manage.

4. Water for Animals

Animals entering the water to drink or bathe are a primary factor destroying the banks of watercourses. When farmers were asked to keep their buffalo and bullocks away from the watercourses they reminded the engineers that the Holy Quran indicates that water is first for man, second for animals, and then for crops, and consequently, they felt that provisions must be made for the animals to use the water.

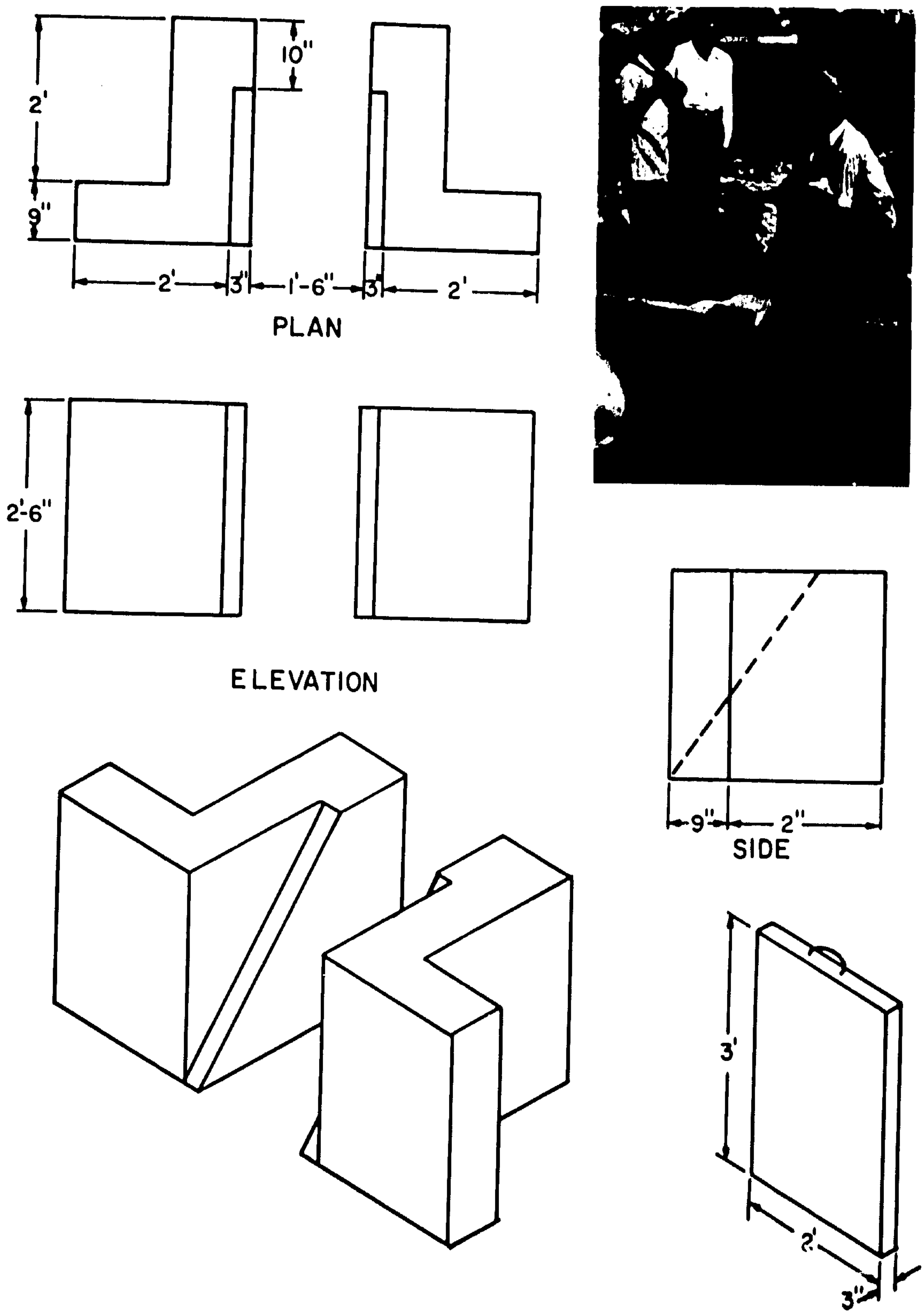


Figure 20. Slide check structure (Akram et al., 1976).

When the only purpose for the animals being at the watercourse is to take a drink, this can be facilitated by a short length of masonry wall serving as the bank of the watercourse on the side from which the animals are to approach. The ease with which the animals can drink and, therefore the probability that their approach to the watercourse will be concentrated at that point is improved if the ground level outside the watercourse is lower than the water in the watercourse at that point.

However, there is a tradition, well established in the minds of farmers, that during the hot weather the water buffalo need to be bathed. This is commonly accomplished by allowing the buffalo to enter sections of the watercourse. At these points, the banks are badly damaged and the watercourse is often deepened and broadened so that it becomes a primary area of leakage. In the process of developing an improvement program with the farmers, it was common for them to agree to limit the bathing of their animals to a few selected points on the watercourse if structures could be provided at those points which would allow easy access for the buffalo to the water at those points and reduce water loss to a minimum. Several types of buffalo baths were constructed at various places along these watercourses (e.g., see Figure 21). The farmers who owned the adjacent land were generally reluctant to donate appreciable quantities of their land to the buffalo baths. However, in a few cases, they were convinced to do this by pointing out to them that they would have the most immediate access to this bath and therefore would be the most benefited. This argument was most effective with farmers who had large animal holdings, lived relatively close together and could be induced to compete for having the bath located immediately adjacent to their animal compounds. However, in general, the farmers wanted the buffalo bath to be within the watercourse itself. It is actually illegal to construct such a structure in the sarkari khal (government authorized common watercourse). However, this law was not enforced and the Irrigation Department actually allows the farmers to do whatever they wish with their watercourse as long as they can agree on what they want to do. Generally, this agreement was obtained and the buffalo baths were built at a junction of the watercourse where the structures controlling the entry of water to two or three branches could serve as part of the wall of the buffalo bath.

One of the least costly and most used buffalo baths was constructed adjacent to the watercourse serving Tubewell 51 with the design indicated in Figure 22. The sandy soil at this location allowed the buffalo to enter the bath without miring into the mud and consequently a masonry or concrete ramp was not necessary. Ramps were the primary cost of many of the constructed buffalo baths because the soil underneath these ramps was commonly saturated and the force exerted by the foot of the

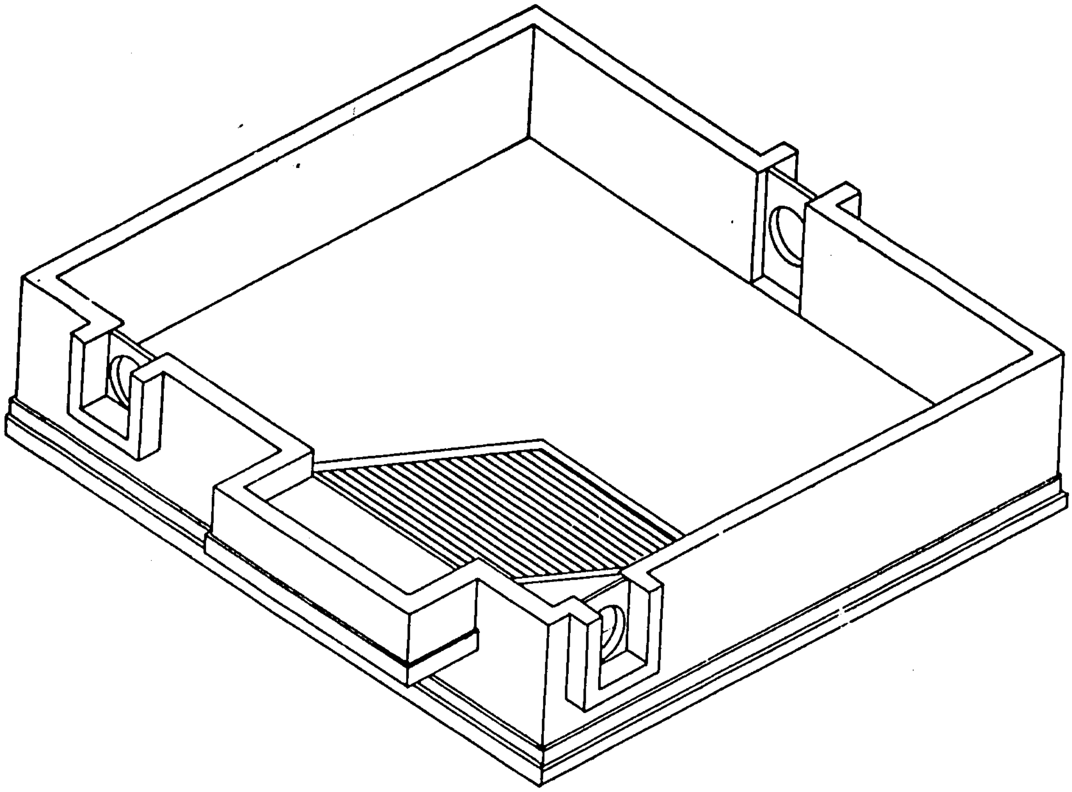


Figure 21A. Typical section of tubewell #56 watercourse prior to improvement.

Figure 21B. Same section as shown in 21A where the banks and channel were built by farmers to the designed size.

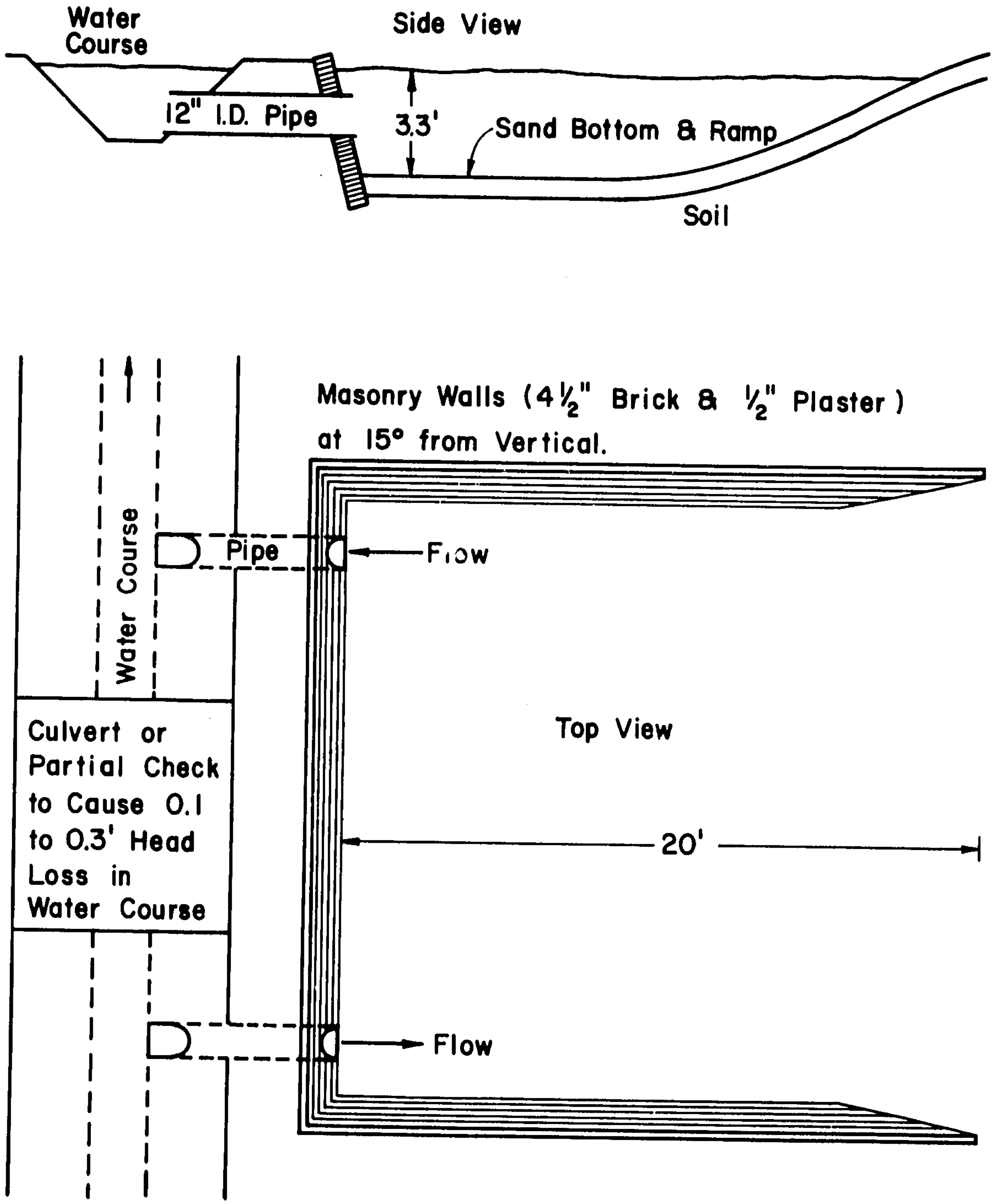


Figure 22. Reasonable cost structure for animal bathing.

buffalo as it comes down this ramp can often exceed 500 pounds. This resulted in a rapid deterioration of the ramps which were first constructed. It was found to be necessary to install a base of gravel or broken brick which was about a foot thick if the concrete or masonry surface of the ramp was to remain intact. For reasons of economy, safety and preference by the animal, it is generally recommended that the ramps to such baths be formed of unconsolidated sand with a slope of about 1:4 or less. Where the soil is not sandy, this sand can be hauled in. Their sand ramp will require some maintenance schedule for the watercourse. These buffalo baths frequently become a social center for the young boys of the area who are commonly the escorts and bathing companions of the buffalo!

5. Water for Washing Clothes

Village women wash their clothes along the banks of the watercourses. Groups of 2 to 10 women can often be found along popular locations beating their clothes with wooden boards on the channel banks, constantly dipping the clothing in the flowing water. Such activity of course leads to a rapid deterioration of the banks at these popular washing spots.

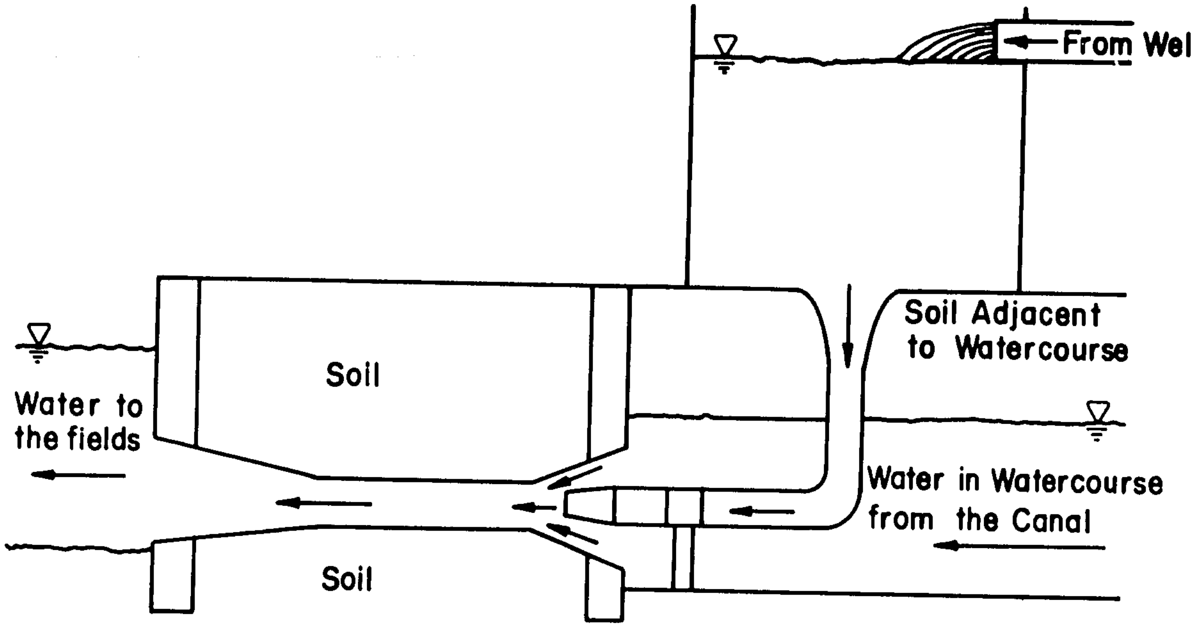
The engineers and advisors considered prohibiting such activity on improved channels for the sake of preserving the watercourse. However, discussions with village leaders quickly convinced them that such a rule would not be wise or enforceable. Consequently, an attempt was made to localize and accommodate the activity. Washing stations were constructed at one or two locations, chosen by the village leaders (or probably by their wives), near each village. These stations consisted of a short section where one or both banks were lined with 9 inch brick masonry vertical walls. A 13-18 inch slab was placed on top of the wall to serve as a washing platform. The top of the slab was designed to be about 4 inches above the normal flowing water surface to allow the women easy access to the water. These washing stations were very popular with local women and were crowded during popular washing periods. They not only prevented bank deterioration but also spread the benefits of watercourse improvement to some groups who would otherwise be less inclined to support the work.

6. Raising Canal Water to High Fields

The outlets (moghas) from the canals to the watercourse in Pakistan were generally designed to operate under free flow conditions or with a given head loss. When wells are drilled which pump water into these watercourses, the increased flow in the watercourses often increases the level of water in the watercourse and reduces the flow of water from the canal into the farmers' watercourses to less than their allocated supply. In most of these cases, a redesign of the watercourse, increasing its cross sectional area, and keeping it clean of weeds and sediments can bring the water in the watercourse back down to its design level so it will carry the well water plus the allocated canal water to the farmer's field. However, there are many watercourses in Pakistan where there are high fields which are difficult to irrigate because their elevations are only a few inches lower than that of the water in the canal. When the farmers owning these fields are irrigating, the level of the water in the watercourse approaches that in the canal and little flow takes place through the outlet. This often results in the water being almost entirely from the tubewell, which reduces the quantity of water received to less than that which is allocated. Perhaps even more important, when the tubewell is pumping water which is marginally saline, the water delivered to the farmer's field is much more saline than if it were diluted by the canal water as was originally planned by the designers of the system.

To solve this problem, jet junctions of the type indicated in Figure 23 have been designed (Aust, 1978). These junctions make use of the elevation energy (3 to 6 feet of head) commonly available in the fall boxes from tubewells in Pakistan. This energy of the tubewell water is used to lift the canal water to an elevation a foot or so higher than the elevation of the water in the watercourse just below the outlet from the canal. This extension of the jet pump to high volume-low lift dimensions has no moving parts and the constricting jet, receiving funnel, mixed chamber and diffusing chamber can generally be manufactured at a cost of about $100. The primary cost is generally the installation, including the concrete pipe or elevated watercourse needed to carry the water from the tubewell fall box to the junction with the watercourse that comes from the canal.

If greater lifts are needed and the pump on the tubewell has sufficient power, the outlet pipe of the tubewell can be connected directly by a pipe to the constricting jet and the size of this jet can be designed to achieve the desired lift. In such direct connections, a one-way valve or standpipe should be incorporated into the highest point of the piping system between the tubewell and the constricting jet, which will allow the air to enter the pipe when the tubewell is turned off and thereby prevent siphoning of the sediment loaded canal water back into the well. Further details of these jet junctions are available in the report prepared by Aust (1978).



A. Side view.

B. Operating (direct hookup to pump) in Pakistan 3 months later.

Figure 23. Basic components of "jet junctions" for lifting canal water to desired levels using energy normally dissipated in the fall boxes of wells in Pakistan.

IV. Farmer Involvement in Solutions Requiring Cooperative Action

A. Branch I of the Watercourse Serving Tubewell 78

Having determined that loss of water from newly-made watercourses with compacted banks was much less than loss of water from the old watercourses, the next step was to see whether farmers could be encouraged to undertake the necessary rebuilding of their watercourse banks. The farmers at Branch I of the watercourse serving Tubewell 78 were approached for this purpose.

They were told that the government would supply concrete control structures and provide the engineering to design the watercourse properly if the farmers would tear down the old banks of their watercourse and build new ones. They were reluctant to do so because neighbors on both sides of them had been given concrete or masonry lined watercourses as part of the research to test costs and benefits of different types of lining.

The farmers' objectives were:

1. To increase the water delivery to their fields;
2. To reduce seepage which was damaging 3 acres of land adjacent to the watercourse.
3. To improve the ease with which the could control their water; and
4. To obtain a watercourse from the government which was as good as those which their neighbors had obtained.

The objectives of the government watercourse improvement team were the same as those of the farmers except for number 4. Here, there was a definite conflict. The primary objective of the government team was to have the farmers do what they could for themselves, and to construct an improved earthen watercourse with concrete control structures which was not the best type of watercourse, but gave the best benefit/cost ratio.

To resolve this conflict of interest, the team coordinator explained to them that the funds set aside for the concrete-masonry lining had all been used, that the improved earthen watercourses with concrete check structures were being considered for a national program, and that they were being asked to be the first farmers to determine what farmers could do for themselves. This "seek not what your government can do for you, but what you can do for your country" approach was not at first successful with most of the farmers. However, two idealistic independent farmers responded and began to work in the face of severe social pressure exerted by the other farmers to hold out for more largess from the government. These two worked alone for three days building the new watercourse which would serve all the farmers, while the rest of the farmers told them they were "fools to work for the government when the government would probably give them a better watercourse if they would hold out a while longer." However, two men continued to work for the common good because they felt farmers should help themselves. The government team coordinator met with the other farmers and told them he would be ashamed to let other men do the work that would bring benefit to him. The next day, one by one, the rest of the farmers joined their strong idealistic friends in moving the earth (Chandawana, 1976).

This branch was 2200 feet long and the farmers completed its reconstruction using about 1100 man-hours of labor. Measurements taken before and after the improvement showed that the loss had been reduced from about 8 percent/1000 feet down to about 3.5 percent/1000 feet. The farmers were pleased with and proud of their new watercourse. The improvement had increased the average delivery to their fields by approximately 0.5 cusecs and this watercourse receives water for 16 hours/week for 50 weeks per year. Consequently, it appeared that the farmers would receive approximately 33 additional acre-feet of water to their fields per year with an investment of about 1100 hours of labor, which is valued at about one rupee per hour; it was apparent that the value of the additional water received in one year would be equal to about three times their investment. While this was a good return, most of the farmers were obviously more impressed by the new concrete control structures which allowed them to control their water with much less effort than they had invested in the old earthen dams.

Elementary economic analysis of the benefits which might be derived from improving a whole watercourse in this manner indicated that the benefits would be at least twice as great for each farmer without the investment of appreciably more labor per farmer. This type of watercourse improvement appeared to be a good investment program for the farmers.

B. Selecting the First Watercourse for Full Scale Improvement

The decision was made to test this potential watercourse improvement program on a full-scale watercourse. Several watercourses in the area were considered and measurements of water loss were taken on each of these to determine their potential for improvement. The watercourse which had the greatest loss was tentatively selected to be the first watercourse to be improved. However, ownership of the land served by the watercourses was also determined and this showed that most of the land served by the watercourse with the greatest rate of loss was controlled by one individual. Discussion of this and other points led to the decision that the watercourse to be improved should be selected on the basis of: 1) having a fairly large number of land holders; 2) having farmers who were cooperative and who had good leaders; and 3) being close to a paved road so that it would be approachable for measurements and demonstration during all seasons.

The rate of water loss became a low priority factor in the selection, partially because all of the watercourses were losing over 40 percent of the water, and because it was decided that the input of good farm leaders would be highly valuable in deciding how a project of this type should be organized. Consequently, good leaders and a reputation of the farmers for working together were the primary criteria considered in selection of the watercourse at Tubewell 56 for the first full-scale watercourse improvement project.

C. Improvement of the Watercourse Serving Tubewell 56

The campaign to interest the farmers at Tubewell 56 began with inviting one of their leaders to see the improvements which had taken place at Branch I of the watercourse serving Tubewell 78. He was obviously impressed with the concrete control structures and was told of the water savings, but these savings were less obvious. He expressed the opinion that the farmers served by his watercourse would be interested in such a program and invited the watercourse improvement team to a meeting with his fellow farmers to discuss this possibility. The watercourse improvement team summarized the information that they had on the watercourse serving Tubewell 56. Before this water reached the farmers' fields, it was losing about 50 percent of the water delivered from the canal and the tubewell. The undersized channel contained considerable silt and sediment, which was raising the level of water in their watercourse so that not all of the water which they were allocated was coming from the canal. The farmers were told that proper design and rebuilding of their watercourse would increase the water delivered to their field by about 30 or 40 percent if they would invest the labor to improve their whole sarkari khal, which was about 28,000 feet in length. They were told that this would require approximately 14,000 hours of labor and that the government would supply the concrete control structures if the farmers would supply all of the labor. This watercourse served about 930 acres and the farmers' leaders were quick to calculate that this would require each farmer to provide about 15 hours of labor per acre of land which he owned.

Most of the farmers were convinced that they should go ahead with the project. However, there were a couple of holdouts. Both were fairly large land holders who had the potential for convincing some of the farmers who were not at the meeting to vote against the program, so considerable attention was devoted to convincing these two gentlemen that they should participate in the program. They were asked to discuss their reasons for voting against the program. One of them said that he did not believe that the watercourses were actually losing as much water as the engineers had reported. The coordinator of the watercourse improvement team happened to know that this man owned land at the head of the watercourse and some other land that was down near the bottom end, so he asked this farmer how long it took him to irrigate an acre of land near the head as compared to near the tail of the watercourse. The farmer replied that it required about 40 minutes of his turn to irrigate an acre of land near the head of the watercourse, but required at least 2 hours to irrigate an acre of land near the tail of the watercourse. As the farmer expressed these facts it became apparent that he was recognizing the potential for improvement and within a few minutes he had convinced himself that he should cooperate with the others.

The remaining farmer was still not convinced and one of the farmers' leaders suggested that they should not make the decision until they were unanimous and so the meeting was adjourned. Two of the farmers' leaders then met with the team coordinator and told him that the remaining hold-out was probably resisting because he had not developed the idea himself and he would probably go along with the project if he could be given some honorary role to play in the program. They admitted that the old rascal probably wouldn't do any real work, but suggested that this man be appointed to the executive committee which would supervise the project, but that sufficient other members be appointed to do the real work. The farmers' leaders were confident that they could achieve the cooperation of all of the land holders if they proceeded in this manner.

At a subsequent meeting of the farmers, an executive committee of four members was elected which included the two major leaders in the area--the leading member of the largest family in the area and the dissident. Following this election, the farmers were asked if they were willing to support the program and the vote was unanimous. Members of the executive committee then met with the team to outline a program in more detail and to define specific objectives. The farmers' objectives were to:

1. get all of the water from the canal that they were authorized for their watercourses (and more if possible!);

2. increase the water supply to the fields;

3. get the concrete control structures installed so they could control their water more easily; and

4. get water to a few high fields in the watercourse area (one of which happened to be owned by one of the executive committee members) which had been extremely difficult to irrigate with the old watercourse without overtopping the banks.

The objectives of the watercourse improvement team were to:

1. design a watercourse which would have had a high delivery efficiency and would serve the farmers equitably;

2. determine the input of farmer labor and engineers and field assistants' time and of bricks, cement, sand and prefabricated control panels and mason's time which would be necessary for the overall improvement program;

3. observe the manner in which these excellent leaders organized work and to convince the farmers that this was in fact their project and that they were the decision makers;

4. obtain agreements from the farmers with regard to future care and maintenance of this watercourse which would achieve lasting benefits for the farmers; and

5. determine the improvement and delivery efficiency that could be obtained in this watercourse.

Most of the objectives of these two groups were compatible. However, there were a few conflicts of interest. For instance, in line with their desire to achieve long term improvement and benefits, the engineers were insistent that the farmers should plan to keep their animals out of the watercourses because this was one of the primary factors degrading the watercourse. The farmers insisted that their animals, especially their water buffalo, needed to bathe in the hot summer months and pointed out that the Holy Quran states that "water is first for use by man, second for use by animals and third for use by crops."

The engineers were unable to argue with this level of authority, but still could not accept the prospects of the rapid degradation which they knew these animals brought to the watercourse. They finally proposed a compromise in which they would design special sections of the watercourse for use by the buffalo and other animals for their drinking and bathing, if the farmers would cooperate and bring their animals to these specific points on the watercourse for these watering and bathing activities. The farmers' leaders tentatively accepted this proposal and contacted all of the farmers in the area to decide where the "buffalo baths" should be located.

Partially because the farmers themselves recognized the damage which the animals did to the watercourses, they all agreed to this proposal. Consequently, the engineers set about designing buffalo baths which would be reasonable in cost and would fulfill the farmers' needs.

Discussions with the farmers indicated that one of their major concerns was that the sediment from the canal water usually accumulated in the first 1000 feet of the watercourse, rapidly filling the bottom of the ditch. This required frequent cleaning of this section of the watercourse and had resulted in huge mounds of unwanted soil along the first 1000 feet of this watercourse. This resulted in covering farmers' fields at the head and making further cleaning and travel along the watercourse banks difficult. An on-site inspection revealed that there was a short section immediately adjacent to the canal, which was also adjacent to a road, where sediment previously cleaned from the canal had been hauled away by bullock carts and trucks to build up gardens and to make sun-dried bricks. The farmers estimated that if all the sediment could be deposited at this location, there was sufficient demand for it for these purposes. The engineers then designed a section adjacent to this outlet from the canal which was a foot deeper and about two feet wider than the rest of the watercourse. They explained to the farmers that the water would run more slowly in this section and that 80 to 90 percent of the sediment would settle out in this 160-foot section. The farmers were delighted with this solution to one of their problems and readily accepted it as part of "their program."

The engineers proposed locations for check structures and outlets and these were discussed with the farmers.

The executive committee decided to do the reconstruction during the time when the water was not in the canal and asked the government engineers to check with the Irrigation Department to find out exactly when this would be. The engineers obtained this information from the Irrigation Department and the farmers scheduled their work to begin the day after the water was turned out of the canal.

The night before this work was to begin, one of the executive committee men dropped by the research project headquarters and the team suggested to him that they begin work at a certain section of the watercourse where they could demonstrate to the farmers how the reconstruction should take place. This single member of the executive committee agreed. The engineers went out early the next morning to get the demonstrations in place and have the stakes in place for alignment of the channel when the farmers arrived at 8 a.m. Eight a.m. arrived, but the farmers did not. At about 8:20 a.m. a messenger was sent to the village to ask whether there had been some misunderstanding. It was found that the rest of the executive committee had decided that the construction should begin at the head of the watercourse, overruling their member who had agreed to begin at the site suggested by the engineers. When this single member argued that they should do what was proposed by the engineers, the rest of the committee reminded him that the government team had frequently told the committee that the farmers executive committee was the decision-making body. Consequently, the messenger was sent back to the government team requesting that they join the farmers.

Realizing that pulling up their stakes, moving their equipment to the top end of the watercourse and setting the alignment there would take over one hour, and thereby delay work on this extremely important first day, the engineers were reluctant to change their plans. It required considerable ego suppression to follow the farmers' decisions.

Having clearly established that they were in charge, the farmers' executive committee accepted full responsibility for the program. Having shown that they had sufficient authority to change plans of government technicians and their foreign advisors, the executive committee members could certainly go to the homes of their less ambitious neighbors and pull them out of bed in the morning if they didn't show up to work! This was actually done for the first few days. Each farmer was assigned to an executive committee man and if the farmer was not on the job by 8:30, the committee man assigned to that farmer went to the farmer's home and literally "pulled some farmers out of bed." One morning the English speaking member of the executive committee was discussing some of the details of the improvement with the foreign advisers. One of his fellow committee members interrupted to tell him that two of the farmers assigned to him were not on the job and that he should not be spending time with these foreign advisers when there were more important things to do!

The sarkari khal is that portion of the watercourse which is cooperatively owned by the farmers and has a right-of-way that can be used for maintenance and passage. Every farmer has a right to have this sarkari khal deliver water to the boundaries of his property. When holdings are split and sold to different individuals, one of these individuals is usually separated from the sarkari khal by the other's land.

The persons separated from the sarkari khal can petition the Irrigation Department to decree that the private ditch which has been used to serve that land be included as part of the sarkari khal so that he will have access to the water. The person who owns the land has a right to protest if there are other possible routes for taking water to that farmer's field. In cases where a protest is made, the executive engineer of the Irrigation Department investigates the situation and makes the ruling.

One of these requests for extension of the sarkari khal had been made and a protest had been lodged. The farmer making the request for extension of the sarkari khal wanted to have the disputed section included in the improvement program and the executive committee considered it highly probable that the section would become part of the sarkari khal. The protesting landowner was adamant that he would not allow construction of the bigger watercourse and installation of the concrete control structures on his land before his appeal was heard. The executive committee had several meetings with the protesting landowner and arrived at the compromise that the disputed section would be properly designed and the earth works completed, but that the concrete control structures, which are difficult to move, would not be installed until the Irrigation Department executive engineer had made his final ruling on the appeal.

The executive committee spent a large portion of its time supervising this project and settling the many problems which arose. Enthusiasm for the project grew. The farmers agreed to work through the holidays and the project was finished about 10 days ahead of schedule. Figure 24 shows a typical section before and after improvement.

The farmers, and especially those who had land toward the tail of the watercourse, were thrilled with their new water supply. Measurements show that the water reaching the field had been increased by about 50 percent. However, when government officials were brought out to see the improvement project, the farmers almost invariably told the government officials that they had doubled their water supply. They were telling this same enthusiastic story to farmers from neighboring watercourses. Within two months from the time of completion of the watercourse serving Tubewell 56, delegations of farmers from all the surrounding watercourses had been to the research project headquarters to petition that they receive similar help to improve their watercourse.

The government water management improvement team and their advisors were still concerned about the rate at which the watercourse could deteriorate. They suggested that the farmers hire a "khal chowkidar," whose job would be to

Figure 24. An improved earthen channel section beside the original channel it replaced.

patrol the watercourse and close all the leaky junctions, ratholes and so forth which were causing observable loss and making such other minor repairs as he could do by himself. This khal chowkidar was also to report cases of rule breaking, such as farmers allowing their animals to go into the watercourse at unauthorized locations, farmers trimming the banks of their watercourse to extend their fields an extra foot so they could add another row of crop and so forth. The khal chowkidar was also to keep track of the depth of sediment in the trap and the height of water in the watercourse, and tell the executive committee when the trap and watercourse needed to be cleaned so they could function properly. The farmers accepted this suggestion and hired a khal chowkidar. However, they only paid him about 33 maunds of wheat per year, which is equivalent to about $100 per year, and they gave him the right to cut all of the grass that he needed from the banks of the sarkari khal. The khal chowkidar promptly bought himself some milk buffalo and went into the dairy business, which occupied more of his time than his water management activities!

The government water management team also suggested that the farmers plan a major cleaning effort each year when the canal is closed. The farmers agreed to this suggestion and later reported that the work necessary to do this was much less than they had expended in previous years before the major improvement had taken place. This apparent acceptance of their suggestion gratified the team members, but illustrated that the farmers had been doing this cleaning annually and were giving the team members credit for some of these ideas when the farmers had already arrived at these conclusions and practices on their own.

D. The Watercourse Serving Tubewell 73

One of the first groups of adjacent farmers requesting assistance were those from Tubewell 73. They were told that the government watercourse improvement team would put them next on the list for improvements, but that it would be a few months before the analyses of the improvements at Tubewell 56 were finished; the improvements at Tubewell 73 watercourse could be planned at that time. The farmers went back to their village, decided that in a few months they would be getting into wheat harvest when they wouldn't have labor available to make improvements. They decided that they really didn't need the help of the watercourse improvement team, but could just observe closely what their neighbors had done and do likewise. Consequently, they began a program of enlarging their channel and building its banks to greater width and height, and had done this to about half of their sarkari khal, when an unrelated theft resulted in a nearly fatal shooting and divided the farmers into two opposing, feuding groups. A large portion of the farmers were put into jail by the police until tempers could cool down.

Unfortunately, measurements of loss were not obtained on this watercourse before the improvements were made by the farmers. However, the engineers did take measurements of the improved and unimproved sections of the sarkari khal and the water losses in the improved sections were only 60% as much per 1000 feet as the water losses in the unimproved sections. Since the potential executive committee for Tubewell 73 was in jail indefinitely, the prospects for cooperative work on this watercourse were considerably reduced, the next watercourse selected for improvement was the one serving Tubewell 51.

E. The Watercourse at Tubewell 51

The Tubewell 51 watercourse was another large watercourse which served over 900 acres. There were 3 or 5 acres of land adjacent to the channel near the head of this watercourse which were out of production because of so much leakage of water through the banks. The worst leakage was occurring in the section where land on one side of the watercourse was not served by that watercourse. The farmers owning that land would not fix the banks of the watercourse because it was not their watercourse, and the farmers who owned the watercourse were not interested in fixing the watercourse because the land being damaged did not belong to them.

The leaders of the farmers at this watercourse serving Tubewell 51 were relatively wealthy, hard working, intelligent individuals, but were not as public spirited as the leaders had been at Tubewell 56. Consequently, they did not command the same level of respect and cooperation from their neighbors. The objectives of the executive committee at Tubewell 51 were:

1. to increase their supply of canal water,[4]

2. to have sufficient water to grow more oranges;[5] and

4/This was particularly important because the tubewell supplying this watercourse was producing water which was marginally saline. As the watercourse existed, when the tubewell was turned on the elevation of the water in the watercourse would come up so high that it restricted the amount of water coming out of the canal and the tubewell water was only slightly diluted by the low salinity canal water when it reached the field. Some of the farmers with good citrus orchards would have the tubewell operators turn off the well when they were irrigating the citrus orchards because they were convinced that the saline water reduced their crop production.

5/They had plenty of land to grow more oranges, but the limiting factor was considered to be the water supply.

3. to obtain as many concrete control structures as possible.[6]

The objectives of the government team were:

1. to determine whether these farmers with their reputation that was about average for co-operation and available leadership would work together to improve the watercourses;

2. to determine whether the improvement program could be carried through wheat harvest and the immediately following season (May and June), which were the months of extreme heat;

3. to build and construct a buffalo bath which would be about half as expensive as those constructed on Tubewell 56; and

4. to design and construct a watercourse on extremely flat terrain that would equitably serve all of the legally commanded irrigated areas.

These sets of objectives were generally compatible, except for the farmers' demands for additional control structures and the engineers' desires to get the water to all of the fields at an elevation where it could properly irrigate the land. The physical basis of the conflict was that a control structure generally causes a headloss or drop in the elevation of the water, and even if this drop is only two or three centimenters, 10 or 12 extra check structures in the watercourse on land with little slope can lower the water level in the downstream areas to a point where it cannot properly serve legally irrigated land. To some extent, this was also a conflict between farmers who had the high lands toward the tail end of the watercourse and the farmers who wanted the extra structures. There were only a few of the farmers who owned such high land, there were many farmers who wanted extra structures, and the executive committee members had been selected from the latter group.

The farmers began their earthen improvements, which progressed reasonably well, until it was time to begin the wheat harvest. Since all of the available labor in the village was needed to help harvest the wheat, the watercourse improvement was stopped when wheat harvest began. During the interim,

6/They had been to Tubewell 56, had seen the concrete control structures there, and during the course of the project, they demanded more and more of these structures.

the engineers from the watercourse improvement team worked with available masons to install some of the structures. As the farmers finished their wheat harvesting and threshing, they began to return to work on the watercourse. The work was not as well organized, or as well done, as it had been on Tubewell 56. The work crews of some of the large farmers would not show up to do their part on certain days, which resulted in these sections being left undone, and when these work crews showed up there was often no one there to supervise them and make sure they did a good job. The break in continuity due to wheat harvest undoubtedly contributed to some of this disorganization.

The conflict between the farmers and the engineers on the watercourse improvement team over the number of structures increased with time. The engineers knew that they should not allow additional structures and that the additional structures were not needed because in such flat watercourses a single check structure can serve all of the outlets upstream for at least 500 feet. The farmers wanted the convenience of having these structures immediately adjacent to their outlets. They went to the coordinator of the watercourse improvement team and told him their side of the argument. To some extent they won the sympathy of the team coordinator and caused dissension within the team.

These dissensions reached the point where the team members and the project director felt they needed some objective individual to rule on the matter. They asked one of the foreign adivsors to go to the watercourse and rule on each of the disputes between the farmers and the engineers. The advisors went with the team to the village where the farmers from this watercourse lived and explained to the farmers, through interpreters, the basis for the criteria as to how many check structures there should be on the watercourses and requested their cooperation so that they could all have a good watercourse.

The government water management team, the advisor and the executive committee and many of the farmers then walked the complete length of the sarkari khal, with each of the farmers in turn presenting his case for wanting more structures than the engineers had installed and the engineers presenting the reasons why the structures had not been installed. In some cases, where there was question as to whether the check structures could actually serve certain outlets, the elevations were checked before the decision was made. Most of the farmers accepted the decisions.

However, one of the committee men arranged to have most of the farmers stay at one point on the watercourse while he took the water management team down to the point on the watercourse where his outlet would be situated. He then presented requests for outlets and an extra check structure which were not needed, were outside the limitations which had been explained to the farmers to some extent before the program began and had been reiterated that morning. The watercourse improvement team tried to explain to this farmer that the number of structures would adequately irrigate his land, especially if he did some land leveling which they would arrange at no cost as an experimental area. The executive committee member insisted that he had to have the extra structures and threatened that if he was not given the extra structures he would resign from the executive committee and would no longer cooperate in the project. He was told that the rules and regulations by which the decisions had been made through the past several hours had to be applied to all of the farmers equally. Consequently, the structures which he was requesting could not be authorized for payment by the project. The team representatives expressed their hope that he would not resign from the executive committee and discontinue his cooperation, which might cause himself and the whole watercourse to lose the benefits of the program.

The committee member did not verbally withdraw his threat to resign, but he grudgingly walked back to the rest of the farmers with the team and continued with the group for the remainder of the decision-making.

One of the other committee members also asked for an additional check structure and said that he would personally pay the cost of such a structure. It was explained that the head loss was the factor of concern in addition to the cost. Since appreciable head loss could not be afforded at that point, a different type of structure would have to be built which would cause negligible head loss but would cost about 50 percent more than the regular structure. The farmer, being rather wealthy, agreed to pay the cost if the engineers would have it installed. At that point, the team members pointed out that any other farmers who wished to do this, including the other member of the executive committee, could do so.

As the group which had started at the bottom of the watercourse approached the head, one of the committee members identified a piece of land which belonged to a widow who lived in the village and said that an additional outlet was needed to properly serve this piece of land. He said that he realized that the outlet could probably not be allowed if the rules were strictly applied that that the widow had no sons in the country to help her. He made a generally eloquent plea for a charitable consideration of her case. Then as he sat down he said, "moveover she will give us all hell if she doesn't get that outlet!" Amid the general chuckles of the group it was understood and recorded that the widow would get her extra outlet.

Right at the head of the watercourse there was a farmer whose land was so high that he could not get canal water up to it. Consequently, he had been watering this land with water from the tubewell, but it required that he block off the watercourse and essentially stop the canal flow while he was irrigating his land. Since this farmer felt that he would not be benefited by the watercourse improvement, he had not cooperated in building the watercourse. The sediment trap which had been built on this watercourse was adjacent to his land and there was a good possibility that it would be necessary to spread some of this sediment over his already high land when the sediment was cleaned from the trap. He long term cooperation was essential. He asked if a separate watercourse could be built which would carry the tubewell water independently to his land. Such a watercourse would have caused several problems, but one of the young engineers conceived a plan, which he sketched out for the farmer on the spot, which showed how a short pipeline connected with the tubewell fall box could achieve the desired purpose. The engineer knew the cost of the pipe so it was proposed to the farmer that if he would pay the cost of the pipe that the engineer would install this personal tap to the fall box for the farmer. The farmer agreed to do so and indicated that he would cooperate with the other farmers with regard to the cleaning, and the sediment trap.

One factor that had helped the day's negotiations was that one of the most respected leaders from Tubewell 56 watercourse had shown up at the meeting that morning. He did not take the floor and deliver a speech of admonishment, but he visited with many of the farmers as their friend and discussed the benefits and problems of a watercourse project in an objective fashion. The manner in which he exerted his influence illustrated the fact that farmers respond to a calm, experienced and objective example who discusses the problems with them with the attitude that he is confident that they will also be objective and reasonable.

After this resolution of the problems between the farmers and the engineers, the work went reasonably smooth and the additional structures were built. However, the monsoon rains began early in July and there was considerable delay in getting the materials to the structure sites because the roads were practically impassable.

The improvement was eventually completed and collected data indicated approximately 40 percent increase of water supply to the fields. The farmers recognized the increase in their water supply, and when a survey was completed in October, there had been 100 acres of new citrus groves planted. In addition, seepage damage was practically eliminated on about 3-1/2 acres of land which is generally valued at between 15,000 and 20,000 rupees per acre. About 29,000 feet of sarkari khal was improved at a cost to the farmers of about 13,000 hours of labor and a cost to the government of about 40,000 rupees for the control structure panels, bricks, sand and cement and the salaries of masons involved in construction of the control structures and a buffalo bath (Figure 21).

F. The Watercourse Serving Tubewell 57

This was a small watercourse which served about 400 acres and passed through a village with a population of about 4,000 people where it was badly deteriorated as a result of its use for bathing animals, washing clothes, and so forth. About two-thirds of the farmers who owned the commanded land lived in this village. The other third lived in a small village where a murder had been committed a few years earlier. This murder had polarized the village so that one group was still vowing revenge and the other group told the team coordinator that they would not personally work with these neighbors on a watercourse improvement program. However, they decided that they could hire landless laborers who would work for them and build their share of the improved watercourse. Since the land of these farmers from this small village was generally toward the tail end of the watercourse, and they lived near the tail end of the watercourse serving Tubewell 56, they were eager to participate in a watercourse improvement program because they knew the relatively large benefits which tail-end farmers derive.

In general, the objectives of the farmers were:

1. the farmers residing in the large village wished to have the section through their village lined with masonry lining;

2. the farmers in the small village at the tail end wanted to increase their water supply;

3. they wanted a sediment trap similar to the one built at Tubewell 56; and

4. they were highly motivated to improve their watercourse because many of them lived in the same large village as the farmers at Tubewell 56, and the farmers served by Tubewell 56 were giving them glowing reports of the benefits, partly because they wanted the watercourse through their village improved.

The objectives of the government water management team were:

1. to see how many check structures and outlets the farmers would build if they were paying for these themselves;

2. to see whether farmers could and would work on a watercourse construction project during the holy month of Ramazan when most faithful Moslems go without food and water from sunup to sundown;

3. to use the improvement program as a training vehicle to help train prospective watercourse improvement personnel from the Agriculture Departments from the three primary irrigated provinces in Pakistan in the physical and extension techniques of watercourse improvement;

4. to see whether a watercourse improvement program could be carried out during the humid and hot monsoon season; and

5. to improve the water and measure the increase in watercourse efficiency.

While some of the objectives of the two groups were compatible, the farmers were definitely not eager to pay for the concrete structures since the program at Tubewell 51 and 56 had both provided these structures from the government research budget. Compromising on these objectives required one extended meeting with the executive committee which the farmers had elected. The government team pointed out to the farmers that construction of the masonry lined section through the village would be an expensive undertaking, costing about 40,000 rupees, which was over twice as much as the cost of all the control structures that would have been needed in the rest of the watercourse. The proposition was put before the farmers that if they would provide all of the labor to haul the bricks and mix the mortar and the masons to lay the bricks, that the section through the village could be constructed for about 30,000 rupees and the government would apply the 10,000 rupees difference to purchase of the materials for the control structures. The farmers would be expected to provide the rest of the cost and the labor for building these control structures.

However, the farmers had a good estimate from their village neighbors, who had land at Tubewell 56 watercourse, on how much labor would be needed to make the earthen improvements and they also wanted their watercourse finished and operational in October when they begin preparing their land for the following wheat crop. Moreover, there was some feeling on the part of at least some of these farmers that they would like to personally oversee the construction of the outlets and check structures which would serve their farms, so that they could assure that a good job was done. Consequently, the farmers agreed to pay for all of the costs of the check structures if the government would pay a contractor to build the section through the village, with the understanding that the farmers would have a right to check the work of the contractor and force him to maintain the specifications with regard to amount of cement in the mortar and so forth. The engineers quickly drew up the plans for the improvement of the watercourse with the Department of Agriculture personnel from the Sind, the Punjab and the North West Frontier Provinces participating as part of their training. They proposed 19 check structures in the sarkari khal, which had a total length of about 12,000 feet. Each farmer who was going to pay for these check structures reviewed the plans with the engineers. Instead of arguing for increases in the number of check structures, the farmers worked in close harmony with the engineers to work out ways in which the numbers of these check structures might be reduced. Ways were found of reducing the total number of check structures needed from 19 to 17.

The government watercourse improvement team then invited the farmers' executive committee to go with them to the city to see the manufacturer who was making the precast panels and lids, which were essential components of the check structure. This manufacturer had been complaining of the difficulties involved in working with the government and in getting payment from them. The farmers executive committee approached this manufacturer knowing how much the government had been paying for the precast panels and lids. They immediately let the manufacturer know that they wanted a discount price. The manufacturer asked them what they would pay and how payment would be made. The farmers replied that if he would give them a good discount they would pay him half at that moment and with the rest to be paid upon delivery. The manufacturer made a few quick calculations and told the farmers that if they would advertise his product with their neighbors he would sell them the panels for 42 rupees each instead of the 60 rupees each he had been charging on government purchases. The farmers executive committee members were delighted, since this was considerably less than they had told the other farmers they might have to pay. Consequently, their fellow farmers would consider that the executive committee had done an excellent job of bargaining in the big city.

This improvement program was pushed very rapidly, and the morale of the farmers was high during construction, even though the weather was hot and extremely humid. It appeared that practically all of the laborers were drinking and eating during the day which was practically necessary to maintain the physical effort involved in remaking the watercourse. A few of them were asked how they rationalized eating and drinking during the holy month of Ramazan. They indicated that this question had been discussed with their Mulvi (a religious leader) who had studied his Koran and concluded that good husbandry of the water which Allah had provided to the farmers was such a good cause that they would probably be forgiven for eating and drinking, which was an obvious necessity if the work was to continue.

As usual there were a few boundary disputes which had to be resolved. In the course of more than 70 years during which this watercourse had been used, the sediment deposition and cleaning processes had allowed some of these courses to creep from the original property lines on which they had been built so that they were off these lines up to as much as 10 or 12 feet. A preliminary survey indicated that this had happened at one corner. The two farmers who owned the land on the two sides of the watercourse were called in to consult with the engineers and the executive committee. The man who would gain land from the proposed change in path of the watercourse was delighted. The other farmer who was losing land, which he had considered to be his, refused to believe that the watercourse could have moved that far and came to the government team coordinator and the foreign advisor to appeal the decision of the executive committee. For a few minutes the government team coordinator and the foreign advisor forgot their roles and began talking to the farmer in an effort to solve this problem. However, they soon remembered that the farmers executive committee was the authority on such matters and that if they entered into such a controversy, farmers who were not happy with the executive committee's decision would constantly be appealing to them. If the coordinator and foreign advisor accepted this role, they would reduce the authority of the farmer's executive committee. Consequently, they told the farmer that he should go back and express his concerns to the executive committee. They then took one of the executive committee members aside and told him that the engineers could make a more precise survey based on old survey markers in the village which had been in place for 70 years if the farmers involved would agree that those markers in the village were legitimate corner posts. It was also suggested that both farmers be allowed to look through the surveyor's instruments so they could see the lines and personally verify the engineer's conclusions. The executive committee member went back and met with the rest of the executive committee and they decided to use this approach with the farmers. The two farmers were taken to the nearby village where two old surveying markers were firmly embedded in concrete. The farmers both agreed to recognize these as legal established survey markers. The surveyors then worked from these markers to determine the correct line, explaining the process to the affected farmers and giving each of them the opportunity to look through the surveyor's instrument at each step. The farmers may not have understood the whole process, but they indicated that they did. The property line, determined on this basis, extended even further into the complaining farmer's field. In fact, if the watercourse had been moved to the exact line, it would have taken out part of a row of high value citrus trees. The committee recognized the large financial loss that the complaining farmer would undergo if these trees were torn out; consequently, they suggested that the watercourse be moved toward the real boundary as far it could without damaging the trees and that the farmer who was regaining his lost land should allow the complaining farmer to use that land until these citrus trees were no longer productive and the grove would be removed. The farmer who was regaining most of his land back agreed to this solution of the problem. The construction proceeded, the executive committee retained their status as the final decision-making body, and the government team coordinator and foreign advisor were not saddled with the major job of considering appeals of farmers who were dissatisfied with executive committee decisions.

When water was first turned into the improved watercourses, there were some problems in the lower portions because the flow of water was greater and the engineers had not taken into consideration the increased head loss at the existing culverts that would take place when the flow of water was increased. When the flow is doubled, the head loss increases by a factor of four. The executive committee approached the government team and their foreign advisor and requested that the government provide larger culverts to handle this situation. However, the budget had been set for this watercourse improvement program and it appeared that certain earthen improvements such as increasing the channel size, building the banks up a little higher and keeping the sediment out of the culverts would resolve this problem reasonably well. The farmers executive committee argued their point very strongly, but in the end they accepted the responsibility of taking care of it themselves as being in accord with the original agreement.

Unfortunately, during the short time available for obtaining data on the losses from this watercourse, the water had been turned out of the canal for a few days and only tubewell water had been flowing. Previous data had established that losses from the watercourse were often reduced to less than 25 percent when the rate of water flow was reduced to half of the normal flow which was occurring in this case. Consequently, the improvement in delivery efficiency under full flow conditions could not be obtained by direct measurement.

However, the farmers are keenly aware of the duration of their water turn and of how many fields they were able to irrigate during that time. Their application procedure is to let the water flow into the small basins until the land surface is practically covered and then they turn the water off. They watch this very carefully and turn the water to the next field as soon as possible, so that they can apply their limited water supply to as many fields as possible. Consequently, one of the team members was assigned to speak with each farmer and determine how long they had taken to irrigate specific fields before and after the improvement. This assignment was completed very quickly and a set of points were presented which showed decreased time required to irrigate an acre of land following the improvement, and increased time required to irrigate an acre of land as the distance from the canal outlet increased. However, some independent checks with a few of the farmers indicated that their irrigation times did not fall precisely on these lines, but there was considerably more scatter. The individual assigned to obtain this information from the farmers had apparently taken data from a few farmers and had manufactured the rest of the points. Consequently, all of the farmers were contacted again and asked about their irrigation times. As suspected, the real data showed considerable scatter from the straight lines indicated in Figure 25. However, the person who had manufactured the first set of data had done a good job of estimating the average line. These surveys, based on the acreages farmers were irrigating before and after the improvements, indicated an average increase of water delivered to the fields of about 50 percent. It is recommended that individuals taking such surveys record the name of the farmer and location of the field so that the data can be checked easily. Such data also can be used to identify farmers who have the greatest potential for improving their water management.

Rather than being a hindrance to the watercourse construction program, the monsoon rains were found to be helpful. These rains, which occur primarily as short duration showers during the day, generally provided rest breaks during which the farmers would sit under the nearest shelter. The rains kept the soil water content at or above the field capacity moisture percentage, which is the proper water content for digging and packing soils into the banks. Most of the workers were not wearing shoes and having the surface muddy for a few hours was no discomfort since the temperature was generally in the range from 80-95^{o}F.

The experience at Tubewells 51 and 57 had indicated that farmers with average capabilities for cooperating and average leaders could carry out this type of watercourse improvement program if a good example of an improved program was close at hand. The remaining question with regard to cooperation and leadership was whether a group of farmers who had intense social cleavages and did not accept anyone in their group as leaders could accomplish such a program with the help of a government team.

G. Improvement of the Watercourse Serving Tubewell XX

This watercourse was selected because the people living in this village had the highest rate of litigation and crimes, such as kidnapping and robberies, of any village in the area. Some of the farmers were taken to see the improved watercourse at Tubewell 56 and they recognized the benefits

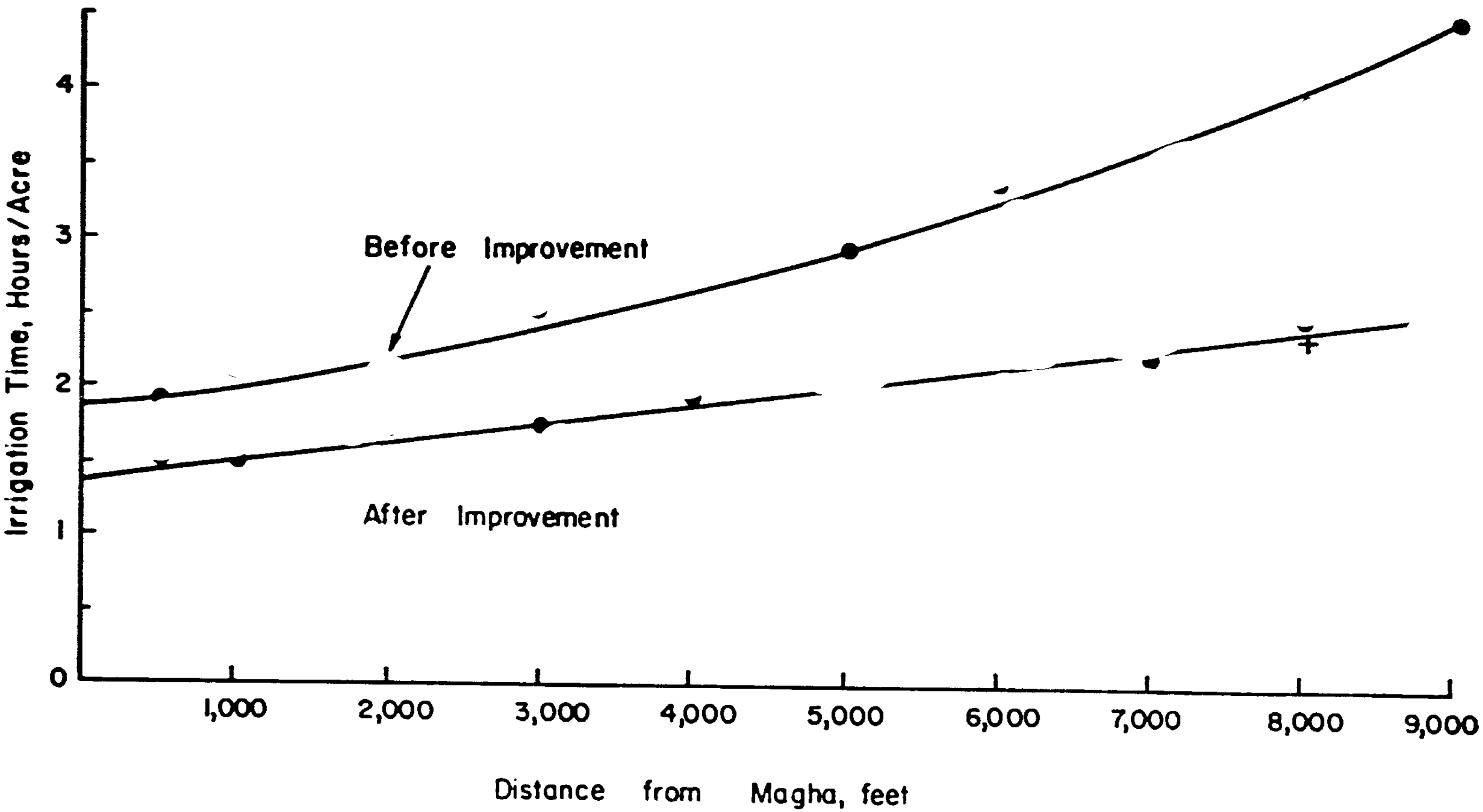


Figure 25. Farmer estimates of time to irrigate fields when tubewells and mogha were all providing water (before and after improvement).

which they could derive from such a program. An intensive 24 hour per day evaluation was conducted on the loss of water from this watercourse through the complete weekly rotation. During the course of this evaluation, many of the farmers developed an interest in what the Mona-CSU field team was doing. The evaluation showed that over 50 percent of the water was being lost from this watercourse. Cash crop production on portions of several fields was not possible because of seepage from the watercourse as illustrated in Figure 26a. One major branch of this watercourse was particularly bad, whereas the other major branch was reasonably good in terms of delivery efficiency. The branch which was losing most of its water had a long stretch where the average operational level was nearly a foot above the surrounding land surface as shown in Figure 26b, whereas the normal operational level in the branch which had reasonably good delivery efficiency was down near the level of the adjacent land. This watercourse served about 400 acres of land. Observations showed that toward the bottom end of the leaky branch several acres were commonly irrigated from another watercourse. This was technically illegal, but the outlet of the other branch was nearer the canal, the land was good and apparently the farmers had made some agreement with persons who owned water from this other watercourse.

The objectives of the farmers in this improvement program were:

1. to improve their watercourses and to increase the delivery of water to their fields;

2. to obtain the concrete water control structures which made handling of their water much easier;

3. to reduce the seepage damage which had eliminated crop production on about two acres of land; and severely decreased crop production on an additional five acres;

4. to obtain improvement of the stretches of watercourse which run through their village, as had been done for the watercourse at Tubewell 57.

The objectives of the government water management team were:

1. to see if these farmers with many social cleavages could work together long enough to complete a watercourse improvement program;

Figure 26a. Seepage damage to citrus seedlings along the watercourse serving Tubewell XX prior to improvement.

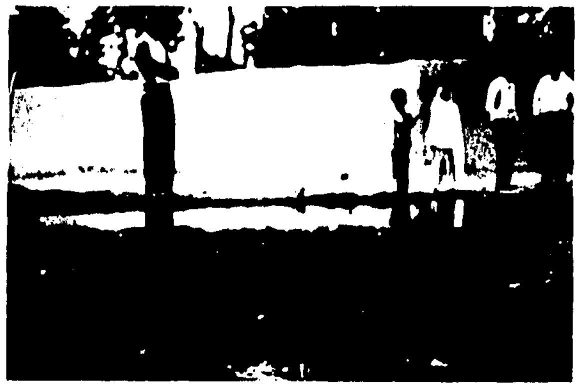


Figure 26b. Leakage from an elevated section before improvement.

Figure 27. Side lining of the watercourse serving Tubewell XX where it passes by the village.

2. to determine whether the farmers would provide the sand and do all of the masonry work involved in constructing all of the control structures;

3. to increase the delivery efficiency, determine the change in delivery efficiency before and after the improvement program, and to see how this differed in the two distinctly different branches of that watercourse; and

4. to keep the cost of the watercourse down to reasonable levels.

As expected, the primary conflict between these objectives was keeping the cost of the watercourses down to reasonable levels and the farmers objective of trying to obtain masonry lining for the sections of the watercourse which ran through their village. Construction of the type of a watercourse provided at Tubewell 57 would have resulted in a cost of nearly 100,000 rupees. Consequently, the proposal was made to the farmers that government engineers would design the watercourse and provide alignment if the farmers would provide the labor for earthen improvements of the channels and that the government would provide the panels, brick and cement for control structures if the farmers would provide the sand, masons and move all materials to the site where the control structures would be built. A few of the farmers "with reputations for the independent attitudes" refused to cooperate in the project. Most of them agreed to the project on the basis of the above ageement.

With considerable help from the extension assistant, who lived in the village and the project coordinator, the earthen improvements were initiated. There were many disagreements among the farmers. The executive committee was unable to resolve some of these and they called on the project coordinator to arbitrate several conflicts. Despite several delays while solutions to these conflicts were being developed, the earth work was completed.

The bricks and cement were delivered to the village along with the precast panels which were needed for the construction of the concrete control structures. The individual farmers then delivered the bricks to their particular check structures, obtained the sand (by excavating it from the bottom of a nearby major canal during closure) and delivered it to the site at which the control structures were to be built. The farmers recruited masons from their village. After these masons had been instructed on how to construct one or two of the control structures, they were able to install the others with very little help other than for the sngineers to set the bed elevations. The farmers were then left to supervise the construction, to make sure it was done according to their desires and that the cement provided at the site by the government was used in the construction of these control structures.

One group of the farmers had suggested that a wall be built along one edge of the watercourse near the cemetery where a breakout through the bank of the watercourse had at one time filled most of the cemetery with water before it was discovered. The cost of materials for their proposal was about 3000 rupees and consequently the engineers suggested that a good thick earthen bank would keep the water out of the cemetery so that the brick wall would not be needed. After a long holiday weekend the engineers checked the supplies and found several thousand bricks missing along with several bags of cement. These were discovered in the wall that the farmers had proposed along the cemetery. None of the villagers ever admitted knowing how they got there.

The villagers kept up a constant campaign for providing masonry or concrete lining in the sections of the watercourses which ran through their village. When they had completed the earthen improvements on their watercourses, they held a big party to which they invited the government watercourse improvement team, the foreign advisors, and the Mona Reclamation Experimental Project Director. A banquet was served, entertainment was provided and then two of the villagers, selected for the purpose, delivered eloquent pleas telling why they needed the pacca lining in the sections of the watercourse running through the village. The guests had expected this and did not make any commitments at that time.

However, experimental tests had indicated that low cost sidelinings of watercourses could decrease the water losses to practically negligible levels. An opportunity was needed for testing these under heavy use conditions such as existed in the village. Consequently, in the course of further discussions with these farmers, it was agreed that the government would provide the bricks and cement needed for these side linings if the farmers would provide the labor, and arrange for the transport of the materials. It was estimated that the materials for these side linings would cost only about 11 rupees per foot and consequently, the 2200 feet of watercourses that needed to be lined would cost the government only a little more than half the cost of the 1100 feet which was improved at the Tubewell 57 watercourse. Side linings made of bricks, plastered and unplastered were installed as shown in Figure 26.

While a reasonably good job was done on the earthen improvements under the guidance of the engineers, the follow-up maintenance recommended by the government team was not conducted and many sections of this watercourse are deteriorating rather quickly. This was probably due to lack of accepted leaders in the village and the fact that a legal organization which would facilitate maintenance had not been formed. Formal organizations with legal authority to force the less responsible farmers to do their part of the cleaning and maintenance are particularly essential to the persistence of benefits derived from a watercourse when there is a lack of accepted leaders in the group.

H. Improvement of the Watercourse Serving Tubewell XXX

Farmers who lived in the same village but were served by another watercourse approached the team coordinator and requested help to improve their watercourse. Their watercourse had a large amount of seepage damage in the upper reaches where the operating level of water in the watercourse was high. This provided an opportunity for the water management team and their advisors to test a hypothesis that they had developed. Studies of losses from watercourses had shown that rate of loss was decreased substantially when the operating level was low in the watercourse. Consequently, they reasoned that a watercourse with its normal operating level at or near the level of the surrounding land would lose less water. Of course, check structures and freeboard would have to be provided to allow checking up the water level at the point of delivery to the fields. Moreover, the high level of water would extend upstream from the check structures for several hundred feet. However, it appeared that the average water level could be kept much lower in a watercourse designed for its normal operating level to be down near the elevation of adjacent land. Consequently, a tentative agreement to improve this watercourse was reached with these farmers.

The objectives of the farmers were:

1. to increase their water supplies particularly toward the lower end of this watercourse where delivery efficiency was extremely low;

2. to obtain the concrete check structures; and

3. to reduce the seepage damage to the lands adjacent to the watercourse.

The objectives of the government water management team were:

1. to determine whether the proposed "low profile" watercourse design would substantially reduce the rates of loss;

2. to evaluate the cost effectiveness and farmer acceptance of several newly-designed check structures used to raise the water level by the extra six inches which was required for this watercourse design;

3. to help the farmers increase their overall delivery efficiency and ability to properly manage their water; and

4. to decrease seepage damage to fields adjacent to the watercourse.

Reconstruction proceeded reasonably rapid although the team coordinator had to arbitrate several disputes. The only major conflict of objectives that became apparent was the feeling on the part of some of the farmers in the upper reaches that they were having to fill up a deeper watercourse and were losing some of the water that belonged to them. They made several attempts to set control structures at level which were higher than the designed bed levels of the watercourse, which would have retained water in the bed of the watercourse upstream from these check structures and eventually would have left sediment in the bottoms of the watercourses and filled them up to levels where the operating water level would have been above the surface of the adjacent land again. One of these check structures which had been installed was removed under the supervision of the team and installed at a lower level.

The farmers expressed definite preferences for certain of the types of check structures used. They were not too concerned about a little bit of water leaking through the check structure as much as they were about the ease of operation. Since leakage through the check structures wets sections of the watercourse which would have to be wetted later anyway, there was not much disagreement between the farmers and the engineers on this point. The topography of the land commanded by this watercourse was such that the watercourse could be designed with outlets to lower fields which allowed complete drainage of the deep section at the head of the watercourse. The engineers considered this to be a good compensating factor because farmers toward the lower end of the watercourse generally receive much less water because of all the losses. When the farmers at the upper ends of the watercourse complained about the deeper watercourse they were reminded that seepage damages to their land along the watercourse were much less than it had been before and consequently, they were receiving considerable benefit. It might have been impossible to obtain cooperation from these farmers at the upper end if they had not had this problem of seepage damage.

One farmer near the head of the watercourse, but on a side branch which had water only during his turn and consequently, did not result in seepage damage to his land, refused to assist the watercourse improvement because he saw no benefits in the program for him. This indicated that some attention should be paid to developing, and advertising to these farmers, benefits which are primarily for them. These will include: 1) the reduction of the seepage damage; 2) culvert crossings, which are more beneficial to farmers at the top end because the water is always in the watercourse at the top end and the channels are bigger at the top end; 3) special jet junctions which can push canal water up on to higher fields using the energy of water in the tubewell fall boxes to lift the canal water as is done in a jet pump, etc. Gaining the unanimous approval and cooperation of all of the farmers served by a watercourse decreases the instances when these people who see no benefits for themselves in the improvement program refuse to yield to the pressures of society and are banished from the circle of friendship and cooperation by their self righteous neighbors who are cooperating in the improvement program. There is an opportunity for engineers and sociologists to work together to design programs for cooperation by farmers which will have high probabilities of achieving cooperation from all concerned because there are specific personal payoffs designed into the program for all concerned. In doing this we should remember that it is not only the farmers who are concerned. The extension agents or program development officers, the administrators of these programs, the trainers of the personnel and so forth must also derive benefit from their efforts if the program is to be delivered to the farmers.

Help of the sociologists and extension experts in developing these types of programs is much more valuable than analysis of why programs have failed, which is about all they can do when they are brought into the program during the operational phase when it is already "over the hill" and failing.

Changes in personnel and the initiation of other projects resulted in a long delay before losses from this watercourse were measured following the improvement. In fact, these measurements were taken incidentally when this watercourse was included, along with others of the improved watercourses, in a cleaning and maintenance study which was supervised by other individuals. The persons who summarized the data from the cleaning and maintenance study had not seen this watercourse and when they reported the data they rechecked it because the losses were only about half of those which were being experienced in the other improved watercourse. This data indicates that this low profile design could be a major factor in reducing the losses from watercourses in Pakistan. Reasons for much lower losses in these low profile watercourses are that the banks of watercourses become more porous with time as worms, insects, and rodents find these to be the ideal place to build homes. When the water level is kept at or below the surface of the surrounding land these holes and their connections into the holes below the surface surrounding the watercourse may fill with water. However, they do not serve to conduct water out onto the surface of the surrounding land, which is the primary cause of major losses and seepage damage.

Although the water level does have to be checked up to several inches above the surface at the point of delivery, if there is reasonable slope to the watercourse this should not extend more than 500 or 1000 feet above the point at which the water is delivered to the fields. This is generally only 5 to 25 percent of the total distance which the water is traveling in this watercourse on its way to the field.

I. <u>On-Farm Water Management Project</u>

Officials from Pakistan government agencies and USAID were invited to the inauguration of the first cooperatively improved watercourse at MONA-tubewell 56 watercourse. The farmers quickly instilled in these officials their enthusiams for both the physical improvements to their water delivery system and the resulting additional water available to them, and for the cooperative process through which the improvements were completed.

The officials immediately recognized the potential benefits to Pakistan agriculture in additional water availability and crop production, and began forming plans for extending the program to the rest of the approximately 80,000 watercourses. They also encouraged MONA to continue their watercourse improvement programs so that methods could be refined and benefits evaluated. The initial plans of these officials evolved into the pilot On-Farm water Management (OFWM) Development Project, administered in the provincial Department of Agriculture and partially funded by USAID. The project involved land leveling and water management extension components, in addition to the watercourse improvement work.

By the time the provincial programs were ready to begin, two watercourses had been successfully completed at MONA, and the MONA engineers and extension staff and their advisors had become the experts in watercourse improvement. They were thus chosen to carry out a first training program for engineers of the new project sent by the various provincial agriculture departments.

During this training session training materials and design guidelines were drafted which served as a basis for future materials [illegible]loped in each of the provinces. Also, the training group a[illegible]ly carried out the improvement of one MONA watercourse, gi[illegible]hem both practial experience and confidence in their a[illegible]ties and the program methodologies.

Although the start of the OFWM program was delayed due to administrative and personnel problems, once the field work began, the watercourse improvement progressed quickly. In the Punjab province where the project was well organized, and where the background work had been done at MONA, 50 watercourses were improved the first year, and approximately 100 the second year. Each improved watercourse involved the rebuilding of about 16,000 feet of earthen channels according to designs provided by project engineers and with labor provided entirely by the farmers organized by their respective executive committee. An average of 6 percent of the total length which passed through villages or other high traffic areas was lined to prevent rapid deterioration. An average of 35 concrete check and turnout structures and 3 culverts provided by the project were installed by masons provided by the farmers on each watercourse. Material costs to the project averaged Rs. 16,000 per watercourse or Rs. 1/ft, 64 percent of which was for lining.

An evaluation of 11 OFWM Project watercourses which had been improved one year earlier indicated that the average conveyance losses to the ends of the improved channels have been reduced from 41 percent to 18 percent and that an average of 21 percent more water was being delivered to the farmers' fields (On-Farm Water Management, 1979). The farmers on the improved watercourses claimed to be irrigating about 40 percent more land per turn with about a 50 percent savings in labor. Their cropping intensities increased 20 percent, cropping patterns shifted toward higher cash crops which required more water, and yields increased 15 to 25 percent on the various crops (part of which could be attributed to higher fertilizer inputs). The OFWM Project estimated a benefit/cost ratio for the improvement process (excluding administrative, design, and supervision expenses) at 3¼:1 (OFWM, 1979). Perhaps the greatest benefits of the program were first the demonstration to the farmers of their ability to act cooperatively for their own benefit, and second, a new respect from the farmers for government agents resulting from the hard work of the project engineers.

Plans are now being formulated to extend the OFWM Pilot Project, which is designed to improve 1500 watercourses in five years, to include all of the watercourses in Pakistan.

J. Essential Improvements

In the process of helping the government design a water management improvement program in which watercourse improvement of this type was to be a major component, and in the initial stages of instituting this program, it became obvious that training of personnel to carry out these improvements would be a big job and it would take many years before the number of engineers needed to design these watercourses could be trained. However, observations of the losses in the watercourse serving Tubewell 73 and sections of some of these other watercourses where farmers had improved their private watercourses without the help of engineers, indicated that most of the improved delivery was obtained if the farmers would simply keep the channels clean and rebuild the banks themselves with some guidelines as to how wide the banks should be, how high the banks should be above the level of the flowing water, and how wide and deep the channel should be. Further testing of such "essential improvements" to see whether they could achieve benefits that were comparable to those of the designed improvements discussed above, and to determine whether the check structures were a necessary incentive for farmers to work with the government officials to complete one of these improvement programs, was needed.

The farmers served by the watercourse at Tubewell 60 were contacted by the coordinator of the watercourse improvement team. He was considerably handicapped by the fact that farmers in the nearby areas had participated in the projects where they had been given the concrete control structures. However, he was able to convince them to do the earthwork.

The field assistant stayed with these farmers during most of the time when work was being done to improve the watercourse. He helped the executive committee maintain some quality control. The training which the field assistant had received to enable him to do this job was a few days of on-the-job experience on previous improvement projects. The role of the coordinator was limited primarily to contacting the farmers, explaining the potential benefits of such a program to them and telling them how much input in terms of labor would be required on their part.

The objectives of the farmers were:

1. to improve their water supply (although they probably hoped that if they did a good job and kept contact with the project that they might receive the concrete structures at a later date).

The objectives of the team coordinator were:

1. to see whether extension field assistants working through the provincial Department of Agriculture, who are rather ineffective in most of the things that they are doing, could be trained and motivated to help the farmers to substantially increase their water supply;

2. to determine whether the procedures which did not require engineering assistance could achieve most of the benefits derived from those which required engineering expertise; and

3. to determine whether the incentive of receiving additional water was sufficient to motivate the farmers in such a program without having the concrete check structures.

The improvements suggested to the farmers were:

1. removal of trees, shrubs and coarse grasses on the watercourse banks which were increasing transpirational loss, causing partial blockages in the channels and making access difficult for detecting leaks, closing leaks and cleaning and maintaining the channels;

2. closing all observable leakages where water was running into adjacent fields from the watercourse;

3. cleaning all the silt, grass and weeds from the channel, and generally increasing its depth by 3 or 4 inches so the normal operational level of water in a watercourse can be lowered 4 to 6 inches;

4. widening and compacting the banks (18" wide at top with about 1:1 slope), particularly at junctions;

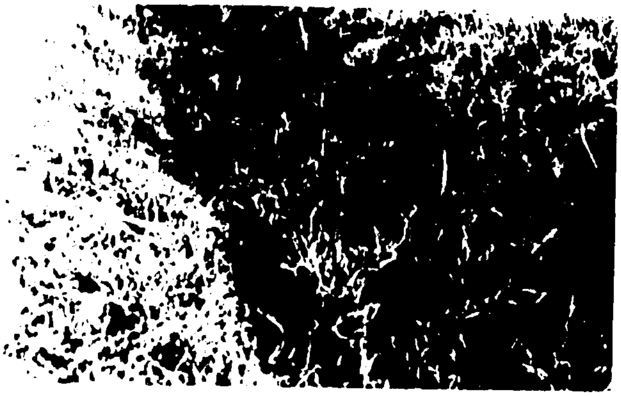
5. filling sections of the watercourse which are so deep that water will not drain out of them, or excavating the channel between these deep sections so that practically all the water drains out of the watercourse into the fields; and

6. filling all borrow pits near the junctions by hauling in soil from high areas in adjacent fields.

The farmers adopted these suggestions as their plan for improvement. Sections prior to, during and following improvement are shown in Figure 28.

The government-authorized sarkari khal included 25,000 feet of watercourse. The executive committee selected the sarkari khal as the portion of the watercourse to be improved. The sarkari khal has a designated legal right-of-way from which soil can be borrowed for the maintenance and improvement of the banks.

Beyond the sarkari khal, each subbranch of watercourse was generally owned by a single farmer and while it is important that these sections be cleaned, the benefits all



A. Grassy section before improvement.

B. A degraded junction with borrow pits full of water and leaking banks before improvement.

C. Improvement in progress.

D. Farmers watching smooth unhindered flow of their water following watercourse improvement.

Figure 28. Sections before and after essential improvement.

accrue to the farmers who makes the improvement. Consequently, the timing and degree of improvement becomes an individual matter to be decided on and implemented by the individual farmer involved.

The 25,000 feet of watercourse were improved by the farmers who spent a total of 6,240 man-hours. The length of watercourse improved per man-hour was 3.7 feet. This is almost twice as much watercourse improved/hour as compared to the regular watercourse improvement program where the banks were pulled down and the watercourse was made precisely straight.

The Watercourse Improvement Project Coordinator spent about 10 hours with the farmers and his Field Assistant spent 130 hours working with the farmers as indicated in Table 4.

Table 4. Summary of Improvement Costs

Source of Work	Hours	Rs./hour	Cost of Work
Farmers	6240	1	Rs. 6240
Field Assistant	130	3	390
Project Coordinator	10	10	100
Total cost			Rs. 6730

Assuming the cost of farmers' labor to be Rs. 1/hour, the Field Assistant to be Rs. 3/hour and the Project Coordinator to be Rs. 10/hours, the costs of the improvement are calculated in Table 4.

The total technical assistance cost to the government of Rs. 490 was minimal. The farmers were not promised concrete control structures or incentives other than the fact that the amount of water delivered to their fields would be increased. In fact, they had the disincentive that they knew that farmers within three miles of their watercourse had been given concrete control structures as part of the regular watercourse improvement program. Consequently, the point was proven that at least some farmers will participate in cooperative watercourse improvement programs with the anticipated increased water supply as their only incentive.

The areas owned, the length of the watercourses from the canal outlet (mogha) to the fields, and the time allocated to each farmer for irrigation were information which could be collected from the farmer and verified from public records. The area irrigated per hour, before and after the improvements, were obtained through interviews with farmers.

The increase in acres irrigated per turn as reported by the farmers averaged about 64 percent. This is higher than has been measured on the watercourse improvement programs at Tubewells 56, 51, 57, 81 and 81L. At these other watercourses, there has been a tendency by the farmers to exaggerate the benefits derived from the improvements. This tendency is a natural result of their feeling that this was their program and their achievement. Most men tend to exaggerate their achievements. It is probable that the long term increases in delivery efficiency will be only about half of those indicated by the farmers.

However, an increase of even 32 percent in water supply to their fields will mean about 360 additional acre-feet delivered to their fields each year. Since the improvement cost was only Rs. 6730, the cost of the additional water would only be Rs. 20 per acre-foot if the same improvement were done each year. The cleaning and maintenance program necessary to keep these watercourses in condition so that they can maintain these delivery rates could require less labor per year than the initial reconstruction. Farmers at Tubewell 56 have indicated that once the watercourse has been properly improved, maintaining it requires fewer hours than were spent before the major improvement. However, these cases are not directly comparable since the farmers at Tubewell 56 received concrete control structures, buffalo baths and culverts, all of which retard the deterioration of the watercourse.

An estimate of the cost of cleaning and maintaining the watercourse at Tubewell 60 (serving about 750 acres) to keep the delivery efficiencies high would be about Rs. 4500 per year, or Rs. 12 per acre-foot of water.

Most of the farmers working at the watercourse were not literate. However, their response was enthusiastic. Their wives and children brought their breakfast to them on the watercourse, indicating their desire to get the job done and a strong component of family participation in the project. Following the improvement program a number of the farmers walked several miles in the severe heat of June to express their appreciation to the extension workers who helped them. Recent reports indicate that the farmers have developed a good maintenance program as they had agreed to do when they planned their improvement program. The farmers are willing to work on the maintenance because they have seen the extra water that they have gained and because they understand the value of the extra water to their crops.

To get out of command (no longer required to pay for irrigation water) a farmer, whose land was at the tail end of the watercourse, had registered a suit in court to be relieved of water taxes. He pleaded that he had not been irrigating his fields since November, 1965 because water was not reaching his fields through the watercourse. Following improvement he withdrew his plea on the basis that he felt he was not "not only receiving water, but receiving my share".

l. Conclusions

Lessons learned included the following. If farmers can be convinced that the government officer has come to them to help them solve their problems, and that he has had successful experiences, they will engage in watercourse improvement projects with no incentives other than the probability of an increased water supply. They will invest their time and energy in such a project when their group decides to go ahead with it.

Farmers perceived that the water supply to their field following this essential improvement program averaged about 160 percent of the water supply prior to improvement. This was a larger increase than has been measured on other watercourses where more intensive improvements had been made. The perception of more increase than has actually occurred is common to other improvement projects where the perceiver has been personally involved as the change agent.

The general tendency of man to overrate his own accomplishments must be considered in developing methods for evaluation of projects. The tendency also emphasizes the importance of letting farmers take leadership in the project as far as possible. The tendency can also be used to good advantage in advertising the program, by bringing the farmers from other watercourses to hear these farmers tell the enthusiastic story of their improvement.

The low cost to the government of this "essential improvement" of the watercourse at Tubewell 60, benefits perceived by the farmers, their enthusiastic participation and the rapidity with which the improvement was accomplished all argue for further consideration of this type of an improvement program to assist the country to bring about a quick increase in water supply to the farmers' fields.

K. Watercourse Cleaning and Maintenance Studies

Watercourse banks were found to have more holes in their upper portions (Kemper, et al., 1975a), causing water loss to be an exponential function of the level of water in a watercourse. Cleaning and maintenance were observed (e.g. Kemper, et al., 1975b) to lower the operating level of water in watercourses by several centimeters. This was due to a decrease in the roughness coefficient of the channel when the vegetation is removed (Akram, et al., 1978). Resulting reductions of water loss from 20 to 50 percent of its value before cleaning have been measured. Based on studies of this type and observations of improved delivery efficiencies following cleaning and essential improvements on watercourses serving Tubewells 73, 60 and parts of 56, it was concluded that a study of the benefits of cleaning and maintenance should be undertaken. Further incentive for this study was the fact that earthen improvements involved in the watercourse improvement phase of the On-Farm Water Management Development Project required the training of extensive numbers of engineers and the installation of concrete control structures which will take decades to accomplish. The short term benefits apparently available from the cleaning and maintenance program appeared to hold promise as a first step in the direction of watercourse improvement which would have rapid payoff. The detailed procedure and results of this study are outlined by Awan, et al., 1978. Some of their conclusions were:

1. farmers perceived a 50 percent increase in water delivery following cleaning and maintenance;

2. average increases in delivery efficiency were about 30 percent when a good regular program of cleaning and maintenance was practiced as compared to the poor cleaning and maintenance that is common on these watercourses;

3. the average farmers "cleaned and maintained" 6 feet of watercourse channel per hour at an approximate cost of Rs. 0.17 per foot during the initial "cleaning and maintenance" which actually involved a considerable amount of reconstruction in many reaches of these watercourses;

4. group social pressure proved effective in convincing reluctant farmers to participate in cooperative programs; and

5. based on the limited number of watercourses studied (about 20) and the limited techniques tried the most successful approach to organizing farmers for cleaning and maintenance appeared to be to hold a general group meeting of the farmers served by the watercourse in which cleaning and maintenance is discussed and the natural leader of the farmers is identified on the basis of participation in the meeting and respect paid to him by the assembled farmers.

V. Further Refinements of the Watercourse Design Process

Refinements of the watercourse design process to maximize water savings and minimizing improvement costs continued during the life of the project. These refinements took primarily two forms:

1. determining simple design techniques that could lead to a further reduction in losses in renovated earthern watercourses, and

2. maximizing the returns to watercourse renovation through an optimum application of improvement techniques.

Trout, Kemper, and Bowers along with several Pakistani engineers and Mona staff members used both operational "inflow-outflow" methods and ponding loss techniques to attempt to quantify and better understand watercourse losses so that improved designs could be intelligently proposed. One of the most dramatic and important findings (e.g., Kemper, et al., 1975b, Trout, 1979, Akram, et al., 1978) was that the loss rates in channels increase very rapidly with and are exponentially related to changes in the flow depth. This finding has the following practical consequences (Trout, 1979):

1. loss rates will increase with increasing channel roughness (Manning's n) and maintaining a clean watercourse should reduce losses by 30 percent over one cleaned only annually;

2. loss rates will increase with increasing flow rates. Supplemental or additional water should not be added to an existing watercourse unless the channels are rebuilt or little of the added water will reach the fields; and

3. upper channel banks have very high water intake rates while channel beds are relatively impervious. Side linings and bank cores should lead to reduced loss rates.

The ponding studies also indicated that channels which are full more often tend to have lower loss rates, probably due to the growth of algae on the submerged wetted perimeter and the inhibition of rodent and insect digging in the banks. Consequently, to minimize watercourse losses, the distribution system should be designed to maximize the usage of a few principle channel sections.

The loss rates in farmers' branches are significantly higher (about double) those in sarkari khal sections. A little less than half of the total watercourse losses occur in the shorter farmers branches. This implies that improvements of the sarkari khal can affect only about half of the total losses. Since loss rates increase with increasing inflow rates, the loss rates in the farmers' branches generally increase when losses are reduced in the main channels, since more water reaches branches. It is consequently very important for the improvement process to extend all the way to the field, even though only low cost improvements, such as thorough cleaning and maintenance, will be economical in the extensive and less often used farmers' branches.

About 7 percent of the inflow to several intensively studied watercourse systems is lost due to transient phenomena. These transient losses include water used during filling to wet dry channels, short term bank breaches and outlet breaks, and dead storage water which doesn't drain into the fields. Most of these transient losses are proportional to the length of channel filled and drained. This implies that transient losses can be reduced either by reducing the number of farmers' branches through field layout changes (i.e., changing from present shapes to longer, narrow fields), or by reducing the number of times a channel is filled. A farmer can reduce the number of times his branch is used by organizing his cropping layout and irrigation timing so that fields he needs to irrigate during each turn are served by the same branch and are adjoining or near to each other. The existing regular turn rotation system helps achieve this objective in the sarkari khal channels. Changing to a demand system in which water is moved back and forth between channels in response to farmer requests would increase transient losses.

Observations during the destruction of old watercourse banks, showed that the upper banks are full of holes. High rate of water loss into the upper banks are apparently caused by leakage into an interconnecting mass of insect, rodent, and worm holes. Most of this leakage never reappears on the soil surface outside the watercourse, but is assumed to infiltrate directly from the burrows which often extend out under the fields.

The watercourse bank environment is a desirable one for these burrowing animals and insects. It is highly organic, providing an ample food supply for its occupants, is often moist and easy to dig, is undisturbed for many years, and, perhaps most important, is one of the few earthen masses of sufficient size which is permanently above water in the level basin irrigated areas. Permanent exclusion of these traditional residents from their desirable homes is probably impossible. Rebuilding the earthen banks will chase out the residents and destroy the holes, but they will usually return and continue their activity. Rebuilding the banks with nonorganic field soils and keeping the banks clean of thick grasses, bushes, and trees will reduce both the food supply and cover for these inhabitants. Thorough bank soil compaction may discourage digging. A poisoning program could limit the community sizes, but must be applied regularly to curb the quickly regenerating populations, and carefully since the conveyed water is used by everyone.

If the insects and rodents cannot be eliminated from the watercourse banks, the next alternative is to design the banks in such a way that their activity does not cause high water losses. Channel lining is a good, although a very expensive means of isolating the holes from the flowing water. Since most holes are located in the upper banks, the partial side linings and cores may be lower cost alternative solutions. Building channels lower in the ground, keeping primary channels full more often, and maintaining a stable water surface level tends to force most burrowing activity higher in the banks and above the level where running water will leak into them.

This complicated biological problem shows the complex nature of watercourse losses. It also emphasizes the need for estimating a life for various types of improvements and techniques over the long run.

A. Optimum Application of Improvement Techniques

Maximizing the net benefits of water-saving watercourse improvements depends upon both the value of the saved water and the cost of a technique which can save a given amount of water. Eckert, et al. (1976) estimated the average value of water in crop production at present and "near future" production levels. When they coupled this with the data obtained by the Field Party on costs and water savings of various types of watercourse improvements they concluded that the economically reasonable first step was to initiate earthen improvements with check structures. These analyses and recommendations formed the initial basis for the watercourse improvement component of the "On Farm Water Management Program" in Pakistan.

Johnson, et al. (1978) estimated the economic value of saved water as a function of the needs for water and amount of water saved. They coupled this value function with the costs of saving water using cleaning and maintenance, earthen improvements and concrete check structures, low cost partial linings and complete concrete and masonry linings. Their analysis supported selection of earthen improvements and concrete check structures as a watercourse improvement program for maximizing the benefits minus the costs. However, it pointed out that the benefits/costs was much larger for a cleaning and maintenance program and that the cleaning and maintenance program does not compete with other sectors of the economy for cement.

Economic analysis of earthen improved watercourses with concrete control structures was completed by the Mona staff (Tubewell 56 watercourse) and OFWM staff (11 OFWM improved watercourses). Both analysis based on actual costs and the value of increased crop production concluded that the benefit cost ratio is between 3:1 and 4:1. (CSU Water Management Field Party, 1977, and OFWM, 1979).

The water savings derived from the application of a technique depends upon the loss rate and the time water flows in the section in addition to the length of the section, while the costs are proportional only to the section length. Consequently, optimum applications must consider channel usage. For example, operational studies indicated that the average farmer's branch section is full only about 2 percent of the time while water is flowing in the average sarkari khal section 36 percent of the rotation period (Trout, 1979).

Reuss (1979) has developed an analysis and procedure which maximizes the benefits/costs ratio of watercourse improvements. This analysis is based on the time of use of the particular sections and the costs and water savings of the different types of improvements studied to date. It indicates that concrete and masonry linings can be economically justified on some of the heavily used sections of the watercourses. He also sets up a procedure which identifies these sections on which lining will be economically justified.

Realizing that there will be locations where channel lining will be desirable, Trout (1979) devised a method of determining minimum cost cross-sectional shapes for given lining material costs. The results, presented in both equation and graphical form, indicate that wider, shallower channels than were normally installed would reduce lining costs.

VI. Research and Development With Manufacturers

The ability of a country to sustain its own research and continue its own development often requires internal ability to manufacture the instruments required for making the requisite measurements and the equipment to facilitate the new technology.

The local manufacture of low-cost accurate flumes to measure flow rates in watercourses was an essential prerequisite of the studies described above and has provided the country with a continuing ability to monitor the efficiency at which their watercourses are delivering water. Achieving a product of satisfactory quality (adherence to prescribed dimensions and utilization of materials which would prolong the useful life of the flume) required frequent consultatiors by CSU Field Party members with the manufacturers in checking all products during the early phases of manufacture.

Control structures were initially made of steel, but economic and field performance evaluations indicated that they were not feasible. The reinforced concrete panels and lids described above evolved as a result of the combined efforts of CSU Field Party members and a local manufacturer.

In both of these cases, the manufacturers were not initially effective in evolving the needed items to fill the needs. They were taken to the field by CSU team members to talk to the farmers and users of the equipment and see the specific conditions under which the equipment was used. Subsequently, they became innovators in their own right, redesigning and building new models which were better adapted to the observed needs.

These manufacturers now understand the value of occassional visits to the field and invest the time to do so.

VII. Impact and Conclusions

The watercourse improvement research described above identified substantial opportunities for improving water supplies to the farmers' fields of Pakistan by improving their watercourses. As soon as it was shown that the benefit/cost ratio of earthen watercourses and concrete check structures could be of the order of 2 to 5, the Pakistan Government and USAID developed a watercourse improvement component of a farm water management improvement program and this was funded by a loan from USAID. USAID and the Pakistan Government requested assistance from the CSU Field Party and their Pakistani cooperators who had been involved in the research to participate in the development and planning and training of personnel for this watercourse improvement component of the On-Farm Water Management Development Project.

The cleaning and maintenance studies indicate that a nationwide cleaning and maintenance program could be initiated which would yield a much higher benefit/cost ratio than the current improvement program and would be a logical first step toward attaining the potential for improved delivery efficiency of the watercourses of Pakistan. It appears, from the watercourse cleaning and maintenance study and the "essential improvements study," that these essential improvements significantly improved delivery efficiencies and can be achieved by farmers with help from extension personnel who have had limited amounts of specialized training.

The watercourse improvement research discussed here was as only a part of the overall water management research conducted by the CSU Field Party and their cooperators. To achieve an economic payoff, the additional water delivered to the farm must be applied efficiently and the crops must be grown efficiently to obtain increased yields. While progress was made in these additional essential research areas, considerable applied and adaptive research is still necessary to help develop the programs that will fully achieve the desired economic payoff. Some of this research has been planned and initiated with the Mona Reclamation Experimental Project and the On-Farm Water Management. Another program developed with the University of Agriculture at Faisalabad is designed to address water application and use efficiency problems and to provide the University personnel with field experience and expertise which will allow them to provide relevant training to personnel for the On-Farm Water Management. There is concern that these research programs may not be carried out as effectively as they could be in view of the current withdrawal of technical assistance by USAID and the departure of the CSU team.

However, in the process of this research, several employees of these agencies have been trained in the types of research and approaches needed and some of these are now in the key positions from which they may be able to guide this research in the directions needed and help develop program implementation on provincial and national scales.

While the political situation between the Government of Pakistan and the United States of America which necessitated the departure of the CSU team from Pakistan is unfortunate, the time was approaching when these research programs could function reasonably well without the expatriate assistance.

In retrospect it appears that the most valuable component of the assistance provided by the CSU team was leadership in going to the fields and helping their Pakistani counterparts gain an understanding of the problems and methods for their solution and an appreciation of the inputs which farmers can make to such solutions.

REFERENCES

Ahmad, Bashir and S.A. Bowers. 1978. Improving Watercourse Conveyance Efficiency Through Cleaning and Maintenance. Improving Irrigation Water Management on Farms, Annual Technical Report, Colorado State University, pp. 427-438.

Akram, M., W. D. Kemper, Iqbal Hussain, William E. Hart, Bashir Ahmed, Sidney Bowers, Javaied Iqbal and Mohammad Azeem. 1976. Pakka Structures for Improved Watercourses, Their Design, Construction and Use. Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries, Annual Technical Report, Colorado State Univ., pp. 151-197.

Akram, Moh'd, W. D. Kemper and S. A. Bowers. 1978. Effects of Cleaning a Watercourse on Rates of Water Loss. Improving Irrigation Water Management on Farms, Annual Technical Report, Colorado State University, pp. 439-459.

Akram, Moh'd, W. D. Kemper and J. Sabey. (1980). Water Losses as a Function of Water Level in Watercourses and Resultant Effects of Cleaning on Delivery Efficiency. Submitted to the Transactions of the American Society of Agricultural Engineers.

Ashraf, M. M., W. D. Kemper, M. M. Chowdhry, Bashir Ahmad and T. Trout. 1977. Review of Watercourse Loss Measurement in Pakistan. WAPDA Monograph #71, Water and Power Development Authority, Pakistan.

Aust, Richard L. 1978. Feasibility and Design of a Low Head Jet Pump for Irrigation in Pakistan. Improving Irrigation Water Management on Farms, Annual Technical Report, Colorado State University, pp. 355-369.

Awan, Mumtaz, Ch. Bashir Ahmad, M. Mohsin Wahla, M. Rafique Gill, Javaid Iqbal and S. A. Bowers. 1978. Watercourse Cleaning and Maintenance Program: Its Organization and Influence on Conveyance Loss. Improving Irrigation Water Management on Farms, Annual Technical Report, Colorado State University, pp. 394-426.

Chandawana, Khan Moh'd. 1976. Pakistan's Future Flows from Water Control. War on Hunger, September, pp. 9-14.

Clyma, Wayne, Arshad Ali and Moh'd Ashraf. 1975. Watercourse Losses. Water Management Research Project Field Report, Colorado State University.

CSU Water Management Field Party and Mona Reclamation Project Staff. 1977. Watercourse Improvement in Pakistan: Pilot Study in Cooperation with Farmers at Tubewell 56L. Water Management Technical Report 45. Colorado State Univ.

Eckert, Jerry, Niel Dimick and Wayne Clyma. 1975. Water Management Alternatives for Pakistan: A Tentative Appraisal. Water Management Technical Report No. 43, Colorado State University.

Huntington Technical Services, Ltd. 1965. Lower Indus Report. Vol. 17. "Distribution Loss."

Johnson, Sam H. III, W. Doral Kemper and Max K. Lowdermilk. 1978. Improving Irrigation Water Management in the Indus Basin. Water Resources Bulletin of the American Water Resources Association, V. 15, pp. 473-495.

Kemper, W. D., Wayne Clyma and Mian Moh'd Ashraf. 1975. Improvement and Maintenance of Earthen Watercourses to Reduce Water Logging and Increase Supplies for Crop Production. Proceedings of the International Conference on Water Logging and Salinity, Lahore, Pakistan.

Kemper, W.D., Wayne Clyma, Moh'd Akram, Moh'd Hanif and Iqbal Parvez. 1975b. Watercourse Losses as Related to Composition and Condition of Banks. Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries, Annual Technical Report, Colorado State Univ., pp. 137-153.

Kemper, W. D. and M. Akram. 1975. Compacted Cores to Reduce Leakage Through Watercourse Banks. Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries, Annual Technical Report, Colorado State University, pp. 243-249.

Lowdermilk, Max K., Alan C. Early and David M. Freeman. 1978. Farm Irrigation Constraints and Farmers Responses: Comprehensive Field Survey of Pakistan. Water Management Technical Report No. 48A, Vol. 1, Colorado State Univ.

Mirza, Ashfaq Hussain. 1975. A Study of Village Organizational Factors Affecting Water Management Decision Making in Pakistan. Water Management Technical Report No. 34, Colorado State University.

On-Farm Water Management Development Project. 1979. Impact of Watercourse Improvement on Farm Production. Punjab On-Farm Water Management Project Report, Provincial Agriculture Dept., Lahore, Pakistan.

Reuss, John. 1979. Optimization of Lengths of Alternative Watercourse Improvement Programs in Pakistan. Improving Irrigation Water Management on Farms, Annual Technical Report, Colorado State University.

Skogerboe, G. V., Abbas Fiuzat, Tom Trout and Rick Aust. 1979. Recalibration of Small Cutthroat Flumes For Use in Pakistan. Water Management Research Project Special Technical Report, Colorado State University.

Trout, Thomas and Moh'd Akram. 1975. Pucca Nucca Losses on Watercourse D Serving Tubewell 78. Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries, Annual Technical Report, Colorado State University, pp. 250-252.

Trout, Tom, S. A. Bowers, Mohsin Wahla, Hayat Ullah Khan, Moh'd. Yasin and M. Iqbal. 1978. Operational Conveyance Losses on Tubewell 81-R Watercourse. Improving Irrigation Water Management on Farms, Annual Technical Report, Colorado State University, pp. 230-272.

Trout, Thomas J. 1979. Factors Affecting Losses from Indus Basin Irrigation Channels. Ph.D. Thesis, Colorado State University.

Trout, Thomas J. and S. A. Bowers. 1979. Operational Irrigation Evaluation of Pakistan Watercourse Conveyance Systems. Water Management Technical Report 52, Colorado State University.

Trout, Thomas J. 1979b. Determining Minimum Cost Cross Sections for Lined Channels. Improving Irrigation Water Management on Farms, Annual Technical Report, Colorado State University, pp. 268-287.