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Additional benefits from reductions in seepage damage to crops and reduced labor at junctions are obvious, but more difficult to evaluate. Maintaining the benefits will require the investment of about 10-man hours of labor per acre foot of water saved. This is some of the least expensive water available in countries where rural labor has a low value during some seasons.

This watercourse improvement appears to be an ideal component for a development program designed to increase crop production.

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WATERCOURSE IMPROVEMENT IN PAKISTAN: PILOT STUDY IN COOPERATION WITH FARMERS AT TUBEWELL 56L

by CSU Water Management Field Party and Mona Reclamation Project Staff

Colorado State University
Fort Collins, Colorado
May 1977

WATER MANAGEMENT
TECHNICAL REPORT NO. 45

WATERCOURSE IMPROVEMENT IN PAKISTAN:
PILOT STUDY IN COOPERATION WITH FARMERS AT TUBEWELL 56L

WATER MANAGEMENT TECHNICAL REPORT NO. 45

Prepared under Support of
United States Agency for International Development
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And the farmers served by Tubewell 56L

Water Management Research Project
Engineering Research Center
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ABSTRACT

WATERCOURSE IMPROVEMENT IN PAKISTAN

Pilot Study in Cooperation with Farmers at Tubewell 56L

Over half the water supplied to the watercourse at Tubewell 56L was lost before it reached the farmers' fields. This loss was primarily through the upper porous portions of the banks and in the vicinity of junctions where banks were thin.

The 35 farmers in the 900-acre area served by this watercourse were motivated to organize themselves to rebuild their own earthen improved watercourse (28,000 feet), according to design specifications drawn up by young Pakistani engineers. Low cost concrete diversion structures were developed and installed at junctions to eliminate continued borrowing of soil and degradation of banks near the junctions. The improvements reduced losses to about one-half their previous values and increased deliveries to the fields by over 50 percent. The cost was about Rs. 2/foot (10RS = $1.00 U.S.) of watercourse improved, including farmers' labor. These costs included costs of experimentation and training and could be decreased to less than Rs 1.5 per foot in a developmental program.

The benefits/cost ratio is based on increased deliveries to the field, on the value assumed for water, and on the interest rate assumed for capital. Additional benefits from reductions in seepage damage to crops and

reduced labor at junctions are obvious, but more difficult to evaluate. Maintaining the benefits will require the investment of about 10-man hours of labor per acre foot of water saved. This is some of the least expensive water available in countries where rural labor has a low value during some seasons.

This watercourse improvement appears to be an ideal component for a development program designed to increase crop production. However, farmers require further information on how to use this water and other inputs to optimize crop production if they are to obtain full benefits from this extra water.

ACKNOWLEDGEMENTS

In addition to the participants listed on the cover page, several other individuals and groups contributed to the studies involved. Appreciation is expressed to the following:

Zafar Ali, Moh'd Ali, Habib Ullah, Nazir Ahmad Shah, Lal Khan and Azeem Ul Din, field assistants from the MREP extension section.

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Muktar Ahmad Kausar, Agricultural Assistant, MREP.

Dr. Alan Early of CSU participated in early discussions of the Pilot Improvement Program.

Dr. Gilbert Corey, former CSU Chief of Party, who insisted from the beginning of the CSU program that the work be with farmers, on farmers' problems.

Most important of all are the farmers who did the work. We wish to express special appreciation to their leaders, Chudhry Moh'd Ashraf, Malik Moh'd Nawaz and Behader Khan, the executive committee of the farmers served by Tubewell 56 watercourse, who grasped the potential for improvement, motivated their fellow farmers to do the work, and showed great wisdom in settling the many questions and disputes that arose in the process of these improvement programs.

CONCLUSIONS

Even though this was an experimental watercourse on which there were many expenditures for experimental structures and many persons were assigned to the watercourse primarily for training, the benefit/cost ratio still appears to be in the range of 3-4. This indicates that in more refined development projects this benefit/cost ratio could be increased to 5 or 6. However, the following findings/recommendations may have an impact on the results of future projects:

*Farmers need help in scheduling maintenance of watercourses.

*Special staff gauges fixed at the head of the watercourse should be painted red in those elevations where the water in the watercourse will cause reduction in flow from the distributary.

*Water losses were generally lower in those parts of the watercourse where water ran continuously.

*Possibility exists to divide water into two or three continuously flowing channels to give farmers more frequent access to water in order to take advantage of low loss rate in continuously flowing channels.

*Sod around culverts and check structures provided adequate protection from erosion in channels where water flowed only one or two days a week.

*Head loss at control structures and culverts may be reduced 10-20 percent if transition structures are constructed.

*Farmers should be instructed thoroughly on methods and time to clean sediment traps.

*Elimination of parallel sub-branches proved completely successful and is highly recommended in future projects.

*Regulations regarding the criteria for location and installation of check structures need to be established prior to negotiations with the farmers.

RECOMMENDATIONS

On the basis of the apparent success of this program the ollowing recommendations are made:

1. Watercourse improvement programs of this type should be included in the On-Farm Water Management Pilot Project to be initiated in the Sind, Punjab and the North West Frontier Provinces of Pakistan.

2. This project should be continued to serve as a training ground for personnel and as laboratories for developing the most effective means of watercourse improvement.

3. Watercourses with permeable soils, steeper slopes, flatter slopes, serving land areas needing additional water and surface drainage should be included in a series of future pilot watercourse projects.

4. Because this project was conducted during December, January, and February when the need for water is low and working conditions are ideal, future projects should be constructed during other seasons of the year.

5. An essential improvement program should be developed and evaluated which would involve a minimal input of capital by government. This might mean constructing compacted earthen buffalo baths rather than masonry ones, and utilizing trained extension field assistants to do much of the engineering under direction of a trained agricultural engineer.

6. Because cleaning and maintenance can cause fluctuations of up to 30 percent in water delivery efficiencies at the tail end of a watercourse, a comprehensive program to define losses, keep to a regular maintenance and cleaning program, and to provide information about cleaning procedures should be instituted.

7. An irrigation advisory service should be developed to provide farmers with an estimate of water flow in their watercourse, amount of water used by the crops since the last irrigation, and the priority need of this crop as compared with other crops which he is growing.

8. Technical assistance and equipment should be made available to farmers who wish to take the advice of irrigation advisors and level their fields.

WATERCOURSE IMPROVEMENT IN PAKISTAN

Pilot Study in Cooperation with Farmers at Tubewell 56L*+

INTRODUCTION

A. Historical

After walking many Pakistan watercourses and observing their generally poor condition, Gilbert Corey and Mian Mohammed Ashraf concluded there was a potential for saving a great deal of water by improving the watercourses that lead from the canals to the Pakistani farmers' fields. Because of this conclusion, Corey, then chief of the Colorado State University (CSU) Water Management Research Project Field Party, and Ashraf, submitted a proposal to the U.S. Agency for International Development (USAID) in early 1972 to test various watercourse improvements in terms of cost, delivery efficiency and longevity. This proposal included an evaluation of land leveling effects on irrigation application efficiency, of improved water scheduling and methods of application

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*Based on studies conducted by the Colorado State University Water Management Research team, the Mona Reclamation Experimental Project and Cooperating farmers. These studies were supported by USAID/Pakistan Agreement No. 204-75 and by USAID/Washington Research Contract No. AID/ta-C-1411.

+Participants in this study, in alphabetical order, include S. A. Bowers, Wayne Clyma, Sam Johnson, W. D. Kemper, and John Reuss of the CSU field party and Moh'd Afzal, Moh'd Akram, Mian Moh'd Ashraf, Moh'd Azeem, Bashir Ahmad, Moh'd Munir Chaudhry and Mohsin Wahla of the Mona Reclamation Experimental Project (also, see acknowledgements)

and of related cultural practices on water use efficiency (yield of crop per unit of water used).

Suggested watercourse improvements ranged from simple earthen improvements to installing 13½-inch masonry walls. Studies by Clyma et al. (1975) showed that only about 50 percent of the water leaving the canal and tubewell was reaching the fields. This indicated a potential for increasing the water supply to the fields by 100 percent if all of the leakage could be prevented. While an economic analysis by Eckert et al. (1975) showed that if the water were used efficiently, masonry-lined channels could be justified, less expensive methods also were found to have high benefits.

Studies on test sections had shown that the water loss from watercourses could be reduced to less than 0.10 cusecs per 1,000 feet if the banks were reasonably compacted and built to proper cross section (Kemper et al., 1975). However, installation of concrete or masonry check structures at the junctions were necessary to eliminate the chronic soil borrowing and bank degradation that accompanies building earthen bunds.

After a number of test sections of watercourses were constructed using contractor or government labor, the farmers thought that it was the government's responsibility to maintain them. Therefore, it was decided that any additional watercourse improvements would be implemented directly to involve the farmers in the planning and construction. Consequently, it was proposed that if the farmers on one branch (I branch) of a test watercourse would provide the labor to rebuild and compact the watercourse to the proper cross section, the research project would furnish improved concrete check structures and engineering supervision. Because I branch was on the watercourse where other branches had been cement-lined at government expense, the farmers at first felt they were being dealt with unjustly and turned the proposition down. However, when the Senior Extension Officer in the Mona Project Area convinced the farmers that no more free concrete-lined watercourses were going to be built, a couple of farmers were convinced. These farmers began work on the watercourse alone in spite of strong pressure from the rest of the group. Their perseverance paid off, and after three days of watching their neighbors work, the rest of the farmers finally joined in the watercourse improvement.

During August the farmers worked on improving their watercourses, and by the time they had finished, the farmers had invested over 1,000 hours of labor in the improvement of 2,200 feet of watercourse. Water losses were reduced from 0.84 cusecs to 0.34 cusecs per 1,000 feet. In some sections where there was obvious leakage, compact cores were installed and showed that the loss rate could be reduced to less than 0.15 cusecs per 1,000 feet (Kemper and Akram, 1975).

B. Criteria Used for Selection of Watercourses

The following criteria were used in selecting watercourses for the pilot watercourse improvement program:

1. Amount of water furnished at the head of the watercourse per acre of land served by the watercourse.

2. Cropping intensity.

3. Fraction of the watercourse supply furnished by the mogha and the tubewell which was being lost by leakage, overtopping, dead storage, etc. from the watercourse.

4. Accessibility of the watercourse to the project headquarters.

5. Accessibility of the watercourse to the nearest pakka road.

6. Size of the land holdings.

7. Known reputation for cooperation by the farmers in the area.

8. Availability of farmers within the group who were progressive and had leadership ability.

Twelve watercourses were initially proposed by the Extension Service Staff as candidates. On the basis of revenue records and Extension Service experience with the farmers in this area, these were narrowed down to six candidates. Measurements of water loss and mogha and tubewell water supply were taken of these watercourses. Ownership patterns also were determined. The watercourse at Tubewell 65 was the top contender until it was found that several of the 50-acre plots were owned or controlled by a single individual; on the basis of this finding it was dropped to the bottom of the list. Of the remaining candidates, the watercourse serving Tubewell 56L was judged to be the best candidate for the first pilot watercourse improvement program according to the criteria cited above.

Meetings were held with the leading farmers of this tubewell, and they were told how much water they were losing. This shocked them into action, and they sent one of their leaders to the farmer-improved branch I of the watercourse at Tubewell 78. He saw the earthen improvement there, participated in the opening and closing of a concrete control structure and was convinced. He, the Senior Extension Officer (Mr. Wahla), and other project personnel went to the watercourse at Tubewell 56L and held a meeting with the other farmers served by this watercourse. These farmers agreed to improve their watercourse under the pilot watercourse scheme. The limited work that had been done on the test branch at Tubewell 78 gave a good estimate of the amount of labor that would be required from the farmers. Because the number of check structures and outlets from the watercourse could be accurately estimated, and because price and cost of installation were reasonably estimated, an accurate estimate of the cost was possible. The farmers were told that they were losing about half of their water before it reached their farms; that they would need to invest about 15,000 hours of labor in improvement of

30,000 feet of their main channel and main branches; and that they would be able to cut their losses in half and increase their water supply by 50 percent. Thus, they concluded that the improvement was a good investment of their labor.

C. Village 10 ML

The majority of the cultivators from the Tubewell 56L pilot watercourse live in the village 10ML. This village dates from the early 1900's when the lower Jhelum Canal was opened. The bulk of the settlers brought into this area were from Gujrat. There are also a few cultivators whose ancestors lived in the area before the canal was constructed (locals), and a few refugees that settled in Village 10ML after partition. Table 1 details the distribution of the cultivators with respect to origin.

Table 1. Origin of the Cultivators of TW 56.

Origin	Number of Cultivators	Percent of Total
Local	3	8%
Settler	31	89%
Refugee	1	3%
TOTAL	35	100%

While the cultivators appear to be almost overwhelmingly dominated by settlers, it does not indicate that they are a homogeneous group.

In fact, there are 10 different castes represented on the watercourse. Table 2 presents the percentage distribution of the castes as well as the number of acres controlled.

Table 2. Caste Distribution and Acreage Controlled by Castes.

Caste	Number of Cultivators	Percent of Total	Total Number of Acres
Arian	2	6%	20.5
Chuhan	1	3%	16.5
Gujar	12	40%	364.0
Gundal	1	3%	18.0
Harral	1	3%	8.0
Janjua	1	3%	7.0
Khokhar	2	6%	129.5
Malik	2	6%	28.0
Raja	1	3%	12.5
Syed	8	27%	230.25

From Table 2 it is apparent that even though there are 10 castes on TW 56, only three castes are dominant in terms of land holding. Gujar, Khokhar, and Syed castes account for over 720 acres. These castes control almost 80 percent of the land on the watercourse and are dominant groups in village 10ML.

Education level of individuals is another relevant variable in terms of influence on the watercourse (see Table 3).

Table 3. Educational Levels for TW 56 Cultivators.

	Level						
	Uneducated	Primary	Middle	Native	F.A.	B.S.	M.A.
Number	15	10	3	2	2	2	1
Percent of totals	43%	29%	8.5%	5.5%	5.5%	5.5%	3%

While over 70 percent of the cultivators are either uneducated or have only primary education, there are enough individuals with higher level education to indicate that this watercourse is, relatively progressive in education. Within the area there is an elementary school, a high school for boys and a village-sponsored handicraft school for girls.

D. Pilot Project Area

The pilot watercourse at TW 56L covers a larger area than most watercourses in the Punjab. The gross area of the watercourse is approximately 928 acres, whereas an average watercourse in Pakistan is roughly 400 acres. However, since one and one-half square (one square = 25 acres) are occupied by the school, graveyard and village, and additional land is taken by roads and a government plot scheme, the cultivable area is only 890 acres. The general details of this watercourse are presented in Figure 1. The Salinity Control and Reclamation Project (SCARP) tubewell and mogha are both located at the head of the watercourse. The amount of water distributed throughout the watercourse varies as a function of the quality of maintenance and, in general, decreases as the distance from the mogha increases.

Over 70 percent of the farms on the pilot watercourse are owner operated (see Table 4).

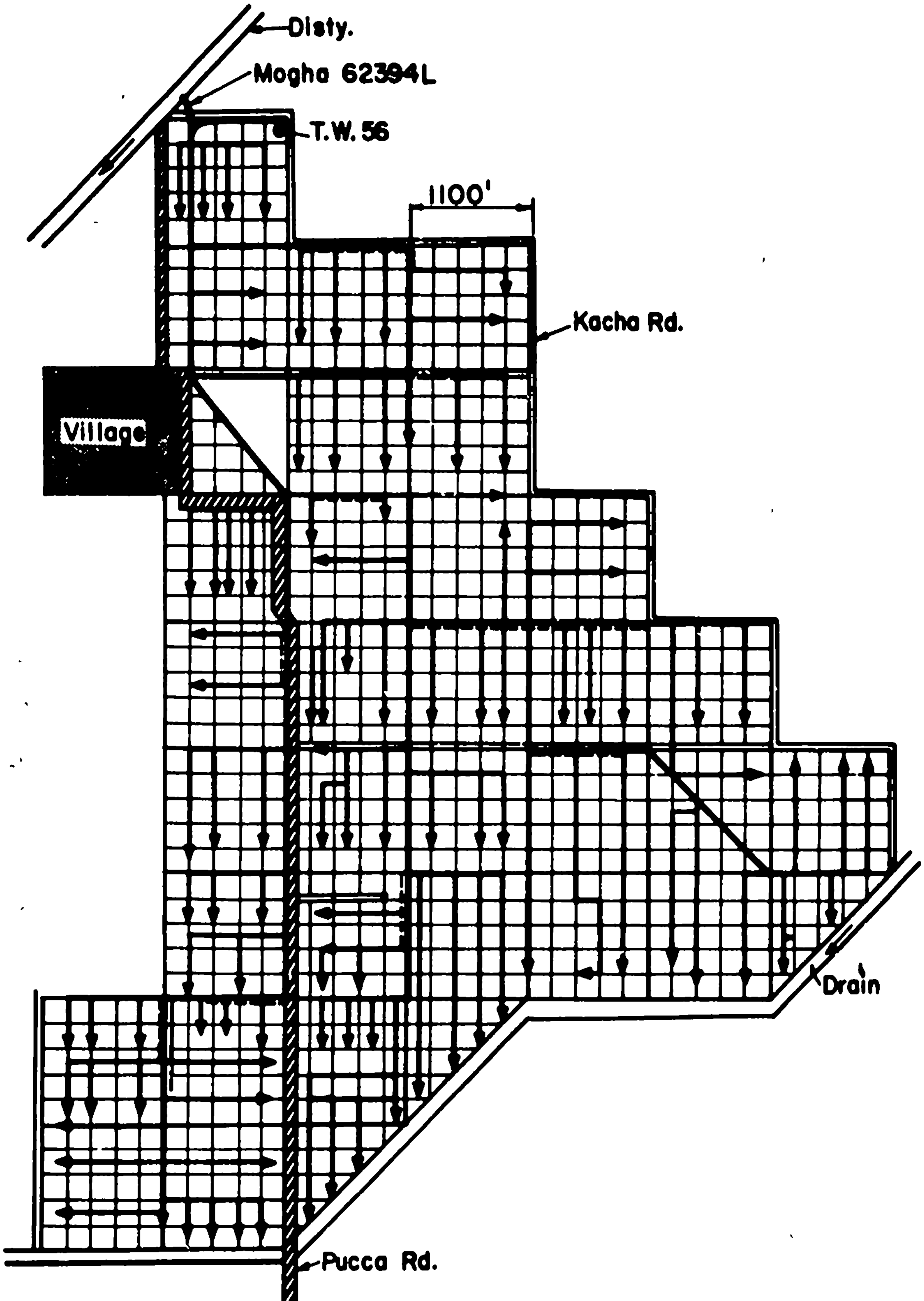

Figure 1. General Plan of TW 56L Watercourse. (Dark lines leading to arrows are watercourses. Dashed lines indicate parallel watercourses which were eliminated in the improved course).

Table 4. Farm Tenure - TW 56 - Fall 1975.

	Tenants	Owner-Cum-Tenant	Owner
Number	7	3	25
Percent of Total	20%	9%	71%

Table 5. Farm Size Distribution.

Farm Size (Acres)	Number	Percentage of Farms
1-12	9	26%
12.1-25	15	43%
Over 25	11	31%

While most of the farms are in the 12-25 acre range, a significant percentage of the farms are over 25 acres. In fact, there are six farms (17 percent) that have 50 or more acres. The average farm size in this watercourse is larger than the average in Pakistan, which is about ten acres. Only 38 percent of the farms are split into more than one area, which is less fragmentation than has occurred in most areas in Pakistan.

The major crops found on the watercourse are wheat, cotton, citrus sugarcane and fodder. Tables 6 and 7 present the cropping acreage for summer (Harif) 1975 and winter (Rabi) 1975-1976.

Table 6. Crop Acreages -Kharif 1975.

Crop	Number of Kanals*	Number Acres	Percent of Total
Sugarcane	408.75	51.1	7%
Cotton	1140.25	142.5	19%
Rice	107.0	13.4	2%
Garden (Citrus)	2086.0	260.7	35%
Lucerne	272.75	34.1	4%
Pulses	15.5	1.9	-
Vegetables	24.0	3.0	-
Melons	349.0	43.6	6%
Tobacco	50.5	6.3	1%
Hemp	20.8	2.6	-
Bajra	814.5	101.8	14%
Jawar	239.4	29.9	4%
Maize	462.0	57.7	8%
TOTAL	5990.4	748.8	100%
Cropping Intensity		83%	

*Note - 1 acre = 8 kanals.

Table 7. Crop Acreages - Rabi 1975-76

Crop	Number of Kanals	Number of Acres	Percent of Total
Wheat	2677.5	334.6	45%
Lucerne	54.7	6.8	1%
Sugarcane	218.2	27.3	4%
Garden (Citrus)	2088.0	261.0	35%
Vegetables	60.0	7.5	1%
Berseem	840.3	105.4	15%
Gram	31.5	3.9	-
TOTAL	5970.3	746.2	100%
Cropping Intensity		82%	

The dominant crops during Kharif were cotton, citrus, and fodder (over 75 percent of the cultivated land), while the dominant crops during Rabi were wheat, citrus and fodder.

Citrus has increased by 63 acres from Kharif 1974 to Kharif 1975, while both cotton and sugarcane acreage has declined.

The yields of the crops vary considerably along the watercourse both in terms of total yields and in terms of yield distribution along the watercourse. Table 8 lists the average yield data for the major crops on the pilot watercourse.

Table 8. Average and Range of Crop Yields in Maunds per Acre for 1974-1975.

Crop	Highest Yield	Lowest Yield	Average Yield
Sugarcane	400 mds/ac	200 mds/ac	268.3 mds/ac
Rice	25 mds/ac	5 mds/ac	17.7 mds/ac
Wheat	60 mds/ac	15 mds/ac	29.8 mds/ac
Citrus[1]	7000 Rs/ac	1000 Rs/ac	3420 Rs/ac
Cotton	10 mds/ac	1 md/ac	5.6 mds/ac
Fodder	400 mds/ac	100 mds/ac	205.0 mds/ac

[1]Citrus is sold on a Rs/acre basis.

Wheat yields are better than the average for Pakistan, but cotton, rice, sugarcane, and fodder are all far below potential. The variation of these yields along the watercourse are listed in Table 9.

Table 9. Distribution of Average Yields Along the Watercourse.

Crop	Head (mds/acre)	Middle (mds/acre)	Tail (mds/acre)	Pakistan Average (mds/acre)
Wheat	48	28	24	13.4
Rice	20.3	13.9	14.1	21.1
Cotton	8.7	6.1	5.2	8.6
Sugarcane	400	237.5	252.6	280.2

From Table 9 it is apparent that the yields are highest toward the head of the watercourse, and tend to decline as the distance from the mogha increases. These yields partially can be explained by the difference in water available along the watercourse. Table 10 presents the average number of irrigations for the major crops with respect to watercourse location.

Table 10. Average Number of Irrigations by Crop and Location.

Crop	Head	Middle	Tail	Overall
Wheat	4.3	3.2	2.4	2.8
Rice	10.3	7.1	10.1	9.1
Sugarcane	5.0	6.2	6.1	5.8
Citrus	3.5	5.3	3.2	3.9
Fodder	7.0	6.0	5.5	6.2
Cotton	2.5	2.2	1.4	1.7

For wheat, rice, cotton, and fodder the number of irrigations (as well as the yields) declines as the distance from the mogha increases.

Five small private tubewells located in the middle and the tail end of this watercourse have allowed the farmers to maintain higher irrigation frequencies and cropping intensities than would otherwise have been possible. However, these wells, with a combined capacity of about four cusecs, have been pumping an average of only about 300 hours per year, for a combined delivery of about 100-acre feet of water/year. Government canal + tubewell supply at the head of the watercourse was about

2,600 acre-feet/year. About 1,200 of this government supply was reaching the fields.

ORGANIZATION AND TRAINING

A. Mona Staff

In order to organize the Mona staff for the pilot watercourse, two types of field staff had to be designated and trained. First, an action field staff was needed to design and implement the project. Second, the research staff was necessary to document the process followed and to gather data measuring the benefits and costs of the project. In an action program that does not contain a research component it would be possible to eliminate the research personnel and just train field staff.

Because successful completion of the project was strongly dependent on the rapport between the project coordinator and the farmers, the Senior Research Officer in Extension, Mr. Mohsin Wahla, was chosen as project co-ordinator. This deviated from the usual practice of placing an engineer in charge, but because the relations with the farmers were good and the farmers were always ahead of the original schedule, this procedure was followed in the two similar projects. Mr. Wahla directly supervised five extension assistants who helped in motivating the farmers to maintain quality control, assisted in data collection, and also gained experience in watercourse improvements. One field assistant would be sufficient in a development which did not include research and training components.

Two agricultural engineers worked on the design, layout and material supply with one additional engineer assisting during the construction phase. The second pilot project used two agricultural engineers, but one agricultural engineer could do the required work. However, absence of an engineer due to emergencies would require backup of another engineer, or training of the field assistant in the use of a level and in the procedures involved in setting the elevations and alignment of the watercourse.

The Senior Research Officer in Economics, Mr. Muhammad Hussain, was in charge of collecting the economics data. The socioeconomic data was collected by his field staff and the extension field assistants. Since the Senior Research Officer of Hydrology was not experienced in data collection, the agricultural engineers were organized to work relatively independently with administrative guidance from the Executive Engineer and technical guidance from the Colorado State University Advisors.

In order to control the project, minimize internal dissensions and assure that all the work was done, it was necessary to define each job and to provide these job descriptions to the field staff (Figure 2 illustrates the organization chart for this project). Even this did not eliminate conflicts. There was the normal amount of disagreement (even among the CSU Advisors), and revisions were necessary. Table II contains a summarized set of job descriptions.

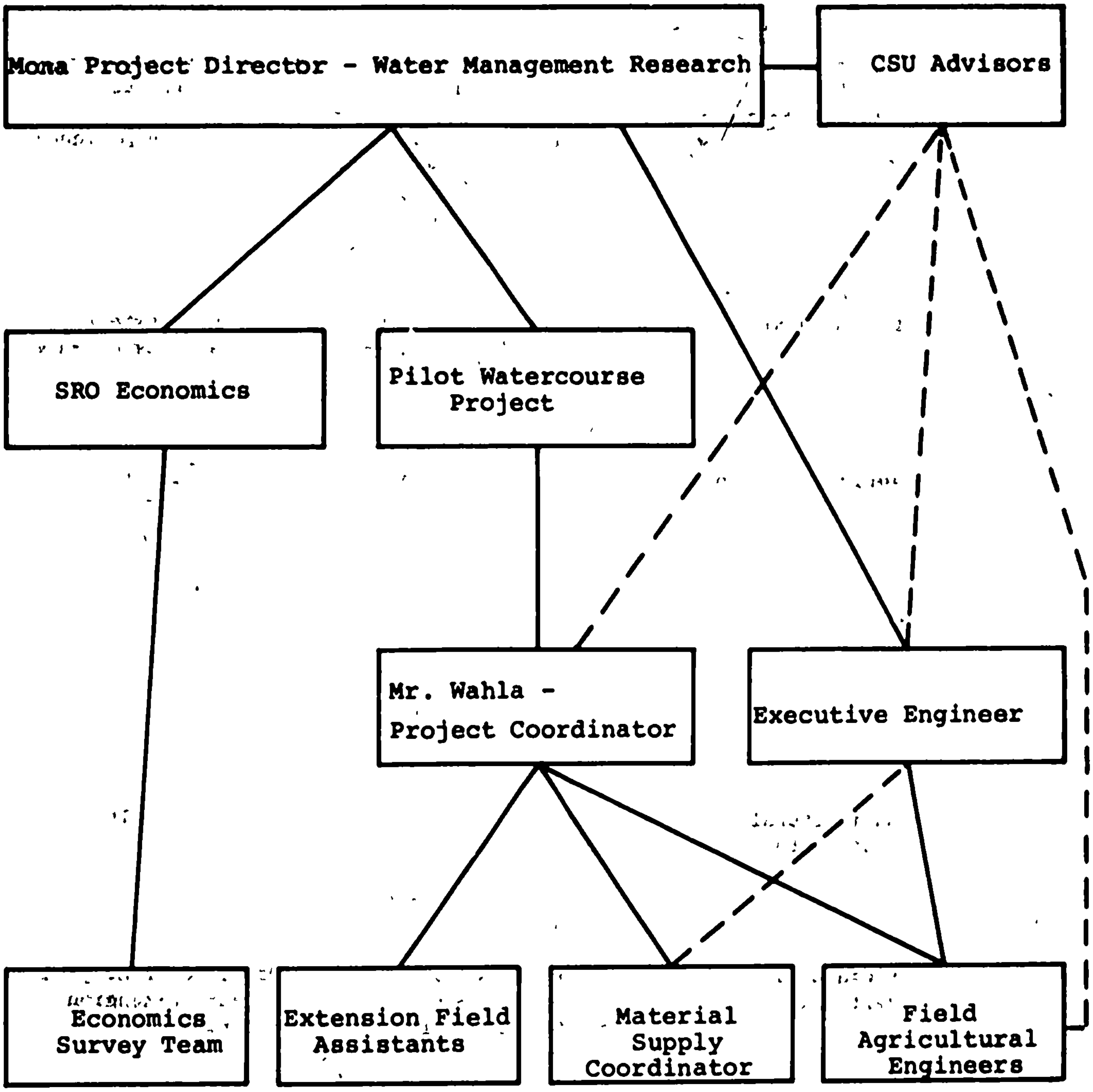

Figure 2. TW-56 Organization Chart.

Table 11. Job Requirements and Qualifications.

Title	Description	Qualifications
Executive Engineer	Handles ordering of materials and supplies and with the MREP Director and Technical Officer supervised the project.	Extensive experience in construction and purchasing
Project Coordinator	Responsible for day to day field decisions-coordinates between field staff and the farmers committee.	B.S. plus extensive extension experience.
Agricultural Engineer	Responsible for all survey work, design, and management of construction. To check for proper elevations, to engineer all improved sections, and to maintain quality control. To plan, with farmers, locations of improved outlets, control structures, culverts, etc.	B.S. Agricultural Engineering
Agricultural Assistants	Responsible for collecting and recording data related to capital and labor inputs to the project.	B.Sc. Agricultural Economics
Field Assistants (Extension)	Responsible for keeping track of labor input by farmers facilitating the organization of work, and maintaining quality control on earthen improvements.	Matric or F.A. plus 2 years extension training.

B. Approach

The most crucial task assigned to the project coordinator, Mohsin Wahla, was the organization of the farmers. He had to win their confidence and obtain an agreement forming the basis for proceeding with the project. The farmers were somewhat reluctant to sign a written agreement; consequently, agreements with the farmers were oral instead of written. However, it was felt that the farmers should have a spokesman to make agreements and speed the implementation process.

The extension staff originally approached the farmers through the field assistant that works on the watercourse. He announced in the village that Mohsin Wahla wished to speak to the farmers. On the given date Mohsin Wahla spoke to 17 shareholders. While this was less than the 35 actual shareholders, these 17 represented the decision-making power of the watercourse. After listening to Mr. Wahla's watercourse improvement scheme, all the farmers but two were excited about the opportunity. Mr. Saleem Shaw expressed doubt about the magnitude of losses on the watercourse, but by considering the time differential between irrigating an acre close to the head and near the tail he was persuaded. Malik Khan Moh'd also was not convinced, and it was felt that his support was crucial. Mr. Wahla solved this problem by selecting him for the first member of the watercourse committee and by letting him make recommendations for the other members. Eventually a four-man committee was unanimously selected. Any other members that wished to join or serve were requested, but the selection was complete because there were two members each from the two major Biradari's (brotherhoods).

At a second meeting the responsibilities of the watercourse committee and tentative plans were presented to the farmers. The duties were the following:

1. Decide all the matters which are in the interest of the watercourse (WC) improvement.

   (a) Selection of the branch to be improved first.

   (b) Installation of nakkas - culverts- buffalo baths, etc.

   (c) Responsible to collect and control the labor.

   (d) Report of any instances of misbehavior to Mr. Wahla.

   (e) Responsible for farmers working all day long and not leaving the WC without permission.

2. Select the date to start the program.

3. Select a Khal numbardar (watercourse leader) to distribute the shares of work at the rate of 6 to 12 sticks (1 stick = 5 ft) per day per 2 squares (25 acres = one square) of land owned. The total rate varies depending upon the degree of difficulty of work on that section of the watercourse.

4. Decide where to direct the water which would ordinarily flow in the branch being improved.

The committee also played a vital role in setting an example for the other farmers. As long as the committee members came early and stayed late, the farmers were also willing to work extra long hours. However, if the committee members took off early, the farmers also were inclined to work a short day.

WATERCOURSE IMPROVEMENT PROGRAM

A. Improvements and Reasons for Their Selection

1. General Program and Layout of the Watercourse Serving Tubewell 56L

The general program for this pilot watercourse was essentially that proposed by Kemper, Clyma and Ashraf (1975) with additional features added as farmers convinced the technical personnel that they were essential. A map showing the watercourse command area and the watercourses within that command area is shown in Figure 1. The dashed lines indicate parallel sub-branch watercourses which were built immediately adjacent to the branches indicated. Figure 3 shows the main channel and the main branches which were to be improved because they are the authorized channels along which there is a right-of-way allowing borrowing of soil to improve the channel. The letters along these sections indicate the designations given to these branches and are in order of the irrigation turns assigned in the waribundi (irrigation) schedule.

2. Concrete Check, Division and Outlet Structures

At most of the major junctions, and many of the minor junctions, the weekly borrowing of soil adjacent to the watercourses to divert from one channel to another had resulted in deep and extensive borrow pits which were commonly full of water. The tendency of the farmers to take the soil from as close to the dam as possible also results in narrowing the banks of the watercourse near

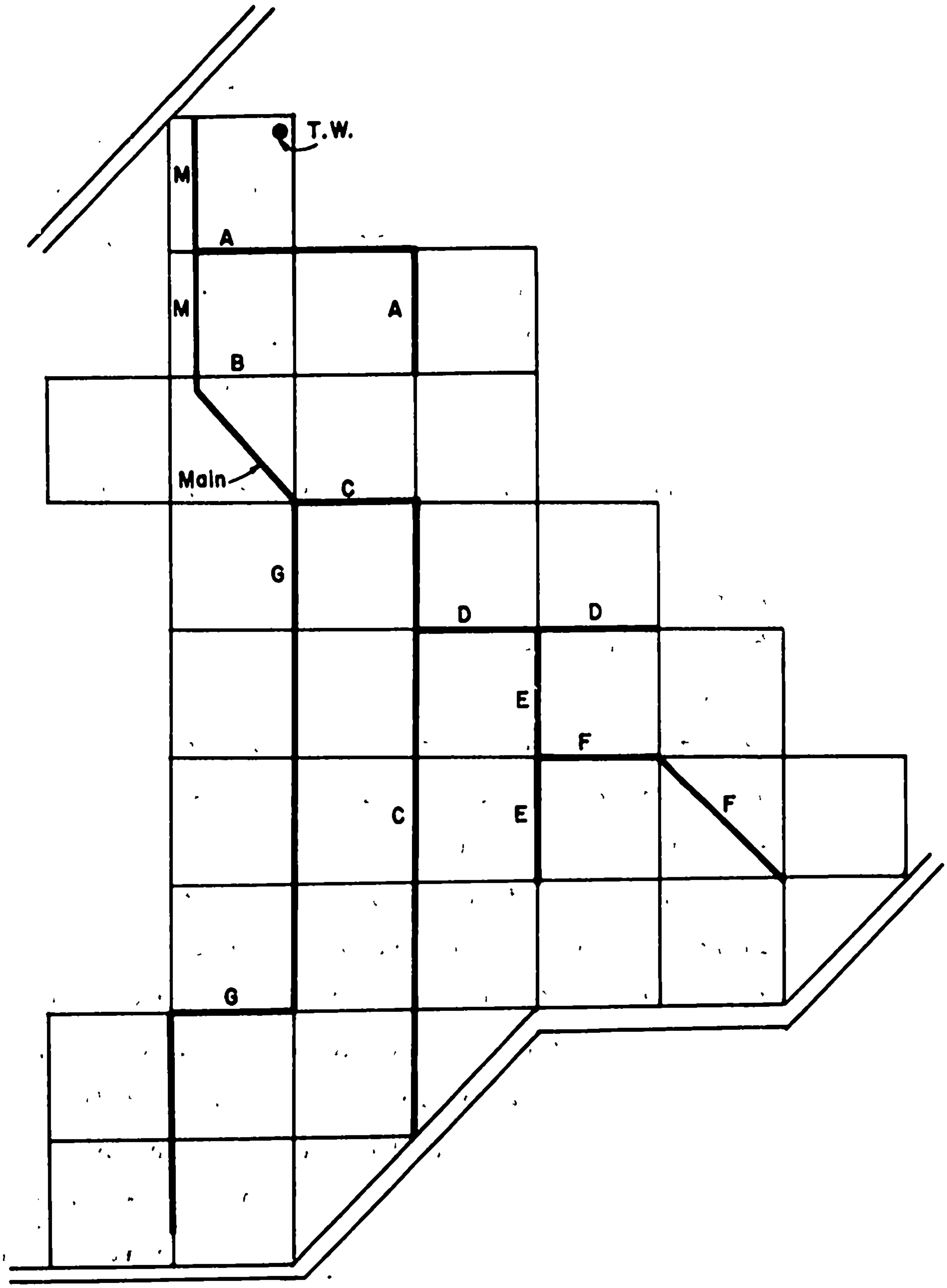

Figure 3. Main Channel and Main Branches (authorized) which Were Improved. (Letters A through G designate branches discussed in text. Heavy lines indicate watercourse channels.)

these junctions so that they become a major source of leakage. In one study (Kemper and Akram, 1975) it was found that 40 percent of the loss from the watercourse occurred within 30 feet of these junctions. A couple of these junctions are shown prior to improvement in Figures 4A and 5A. These same junctions are shown in Figures 4B and 5B following the filling of the borrow pits and the installation of the concrete structures (which eliminate the need for weekly borrowing of soils).

3. Elimination of Sub-branches Parallel to Main Channels

There were about 8,000 feet of sub-branches which were parallel and adjacent to the branches of this watercourse. These parallel sub-branches were designed to reduce the number of nakkas taking off from the main branches by irrigation department officials who recognized that a large portion of the loss from the watercourse occurred at these junctions in the watercourse. However, as shown in Figure 6, the farmers commonly trim the bank between the branch and the parallel sub-branch until it is less than a foot thick. Our measurements indicate that this trimming resulted in an average of almost 0.10 cusecs more loss from the watercourse per 1000 feet in sections of the watercourse where these parallel sub-branches had been built. In general, the installation of two additional outlets can eliminate the need for these parallel sub-branches which are commonly 900 feet long. Thus, if these

Figure 4A. Typical section of Tubewell #56 Watercourse prior to improvement.

Figure 4B. Same section as shown in Figure 6 where the banks and channel were built by farmers to the designed size.

Figure 5A. Degraded junction prior to improvement.

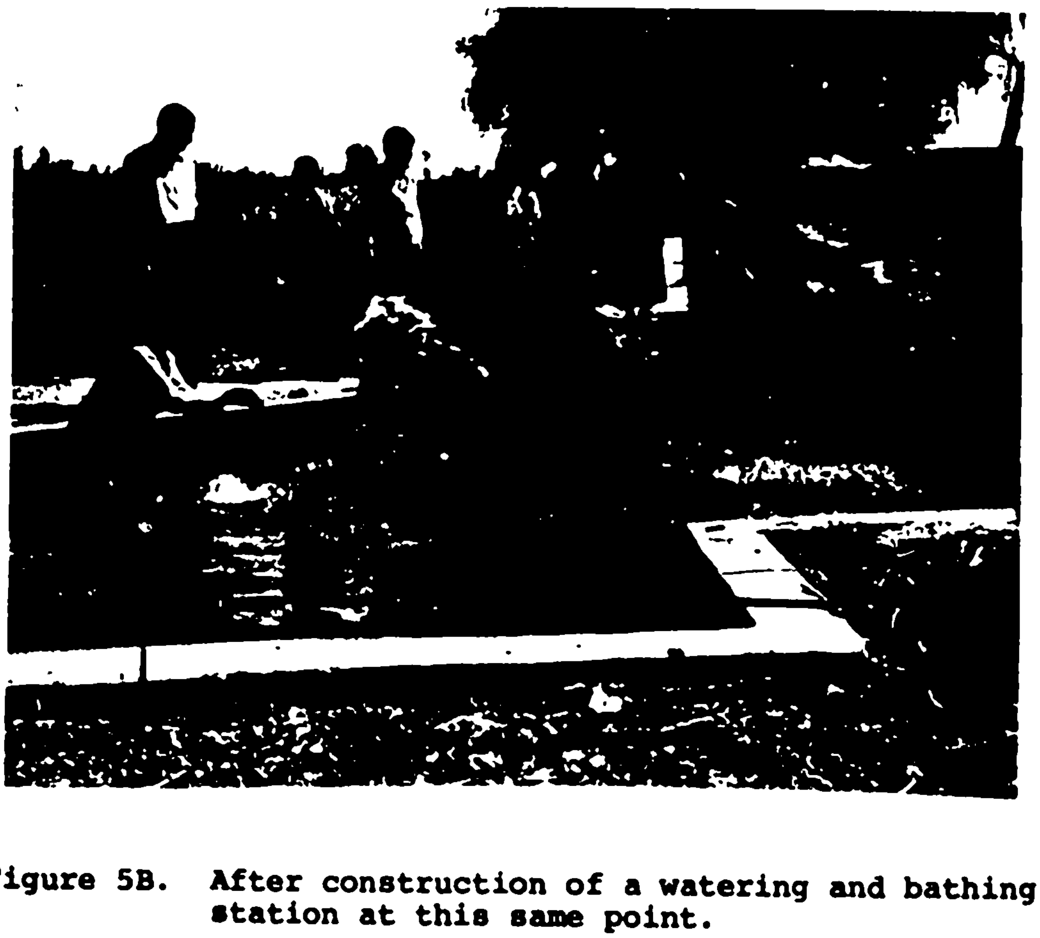

Figure 5B. After construction of a watering and bathing station at this same point.

Figure 6A. Parallel main and branch watercourse separated by trimmed bank.

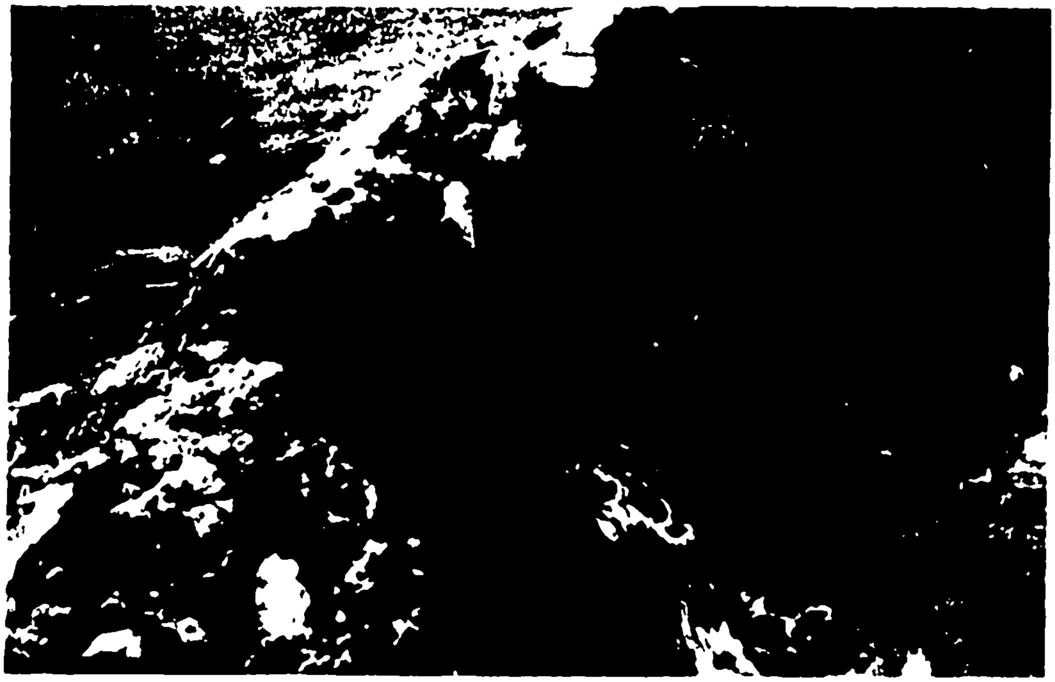

Figure 6B. Leakage through trimmed bank to the branch when water was in main watercourse.

outlets have closures which leak less than .045 cusecs of water on an average, there will be a net gain in water delivery efficiency through the main channel if the parallel sub-branches are eliminated. Data collected by Trout and Akram (1975) indicate that the concrete panel nakkas, even when not properly sealed, leak less than this amount of water; consequently, the parallel sub-branches were eliminated and the additional outlets installed.

In addition to increasing the delivery efficiency of the main channel, elimination of these sub-branches has additional benefits for the farmer who was served by these channels. Most of these channels have considerable dead storage space which must be filled each week. On the particular branch on which this was actually measured, it was found to be 2000 cubic feet in a 900-foot section. Subsequent observations indicated that this dead storage space on this sub-branch was more than the average, but even if the average was only 1000 cubic feet, filling the sub-branch 44 times a year would result in wastage of about one acre foot of water per year. Assuming this water has a value equal to the cost of SCARP tubewell pumped water delivered at the field of about Rs. 100[1] per acre foot, a 100 rupee per year savings to the served farmers can be attributed to the elimination of this dead storage loss.

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[1]10 Rs equals approximately 1 U.S. dollar.

These parallel sub-branches also take a strip of land about 8 feet wide and 900 feet long out of cultivation. Land in this area is leasing at a rate of about Rs. 300 per cropping season, or Rs. 600 per year. When the farmer levels the parallel sub-branch and puts this land into cultivation, he gains approximately Rs. 100 per year in terms of increased farming areas.

In spite of the benefits, not every farmer was eager to do away with parallel sub-branches because some farmers had been using these branches as a water collector to take water from the main channel through the leaks to their fields each week when the water was turned into that branch. Shaving the banks to only a few inches thickness is often a deliberate attempt to increase this illegal water supply. However, most of the other farmers recognized this thievery as detrimental to the group as a whole, and they did not object to elimination of the parallel sub-branches.

4. Lowering the Head of this Watercourse to Allow in the Authorized Canal Supply

When the tubewell was turned on in this watercourse, the water level rose so high that less than half of the water authorized from the canal to this watercourse actually entered through the mogha (which was an open flume type of water diversion structure). The effect of the height of the water in the watercourse on the amount of water coming through the mogha was determined by placing a flume between the mogha and the junction where the tubewell and canal waters came together when the tubewell was turned off. Then the tubewell was turned on and the water level in the watercourse began to rise. The rate of flow to the flume was measured and plotted against the difference in elevation between the water in the distributary and water in the watercourse above the flume. These data showed that if the water in the watercourse were at least three inches lower than the water in the distributary, there was no appreciable reduction in the flow of water through the mogha. In other words, a condition of free flow was achieved which would bring in the amount of water authorized to this watercourse. However, recognizing that there will be times when the watercourse needs some cleaning and may not be in design condition, it was decided to lower the designed fully supply level of water at the head of the watercourse to 6 inches rather than just 3 inches below the distributary full-supply level. This required an overall deepening and in many sections a widening of the watercourse to reduce the friction losses and allow a smaller grade.

5. <u>Elevation and "Freeboard" Required to Deliver Water to All Fields</u>

The elevation of the full supply was designed to meet the following criteria:

(a) Just below the mogha was to be 0.5 feet below the full supply level in the distributary.

(b) At the outlets into the fields the full-supply level was to be 0.5 feet above the level of the fields.

(c) The full supply level in the improved branches was to be sufficiently high to allow a head loss of at least 0.3 feet per 1000 feet of the farmers sub-branch leading to the fields.

It was not always possible to meet all of these criteria. For instance, there are about 25 acres of land near the mogha where the soil surface elevation is only about one-half foot below the elevation of the water in the distributary. To get water onto this land there is no practical alternative other than to let the water rise in the watercourse until it runs out onto the land--at which point the mogha flow is somewhat reduced. This need for raising water in the watercourse to an exceptionally high level for these fields resulted in a design which required an extra 6 inches of free board at the top end of the watercourse. In general the designed free board was 0.5 feet in the branches, 0.67 feet in the main channel except for the top 1,110 feet of the channel where free board of one foot was designed to take care of the aforementioned problem.

6. Design and Roughness Coefficient

The cross section and slope of the watercourse were designed by the Assistant Agricultural Engineers at Mona using CSU's "Aids for Watercourse Design and Improvement" in accord with Manning's equation, assuming a roughness coefficient of 0.04. Use of this 0.04 value was based partially on accepted practice and partly on measurements of this coefficient in newly built or newly cleaned channels of 0.035 and measurement (i.e. Trout and Akram, 1975) which show that this coefficient rises rapidly as vegetation begins to grow in the watercourse. Top width of the banks was set to be at least 1.5 feet, and because the inside and outside slopes were designed at one to one, the minimum width of the banks at the full supply level was at least 2.5 feet. In those stretches where the free board was one foot, the minimum width of the banks was at least 3.5 feet at the full supply level. Maintaining these banks at these widths is important because the probability of insect or rodent holes penetrating completely through the banks is greatly reduced when these banks are thicker.

7. Sediment Removal and Use

In several portions of this watercourse which were rather flat, sediment was deposited in the watercourse. Its removal during cleaning operations extended the banks onto the farmers' land requiring that they either lose the use of that land, or that they spread this sediment over the land surface and relevel their land. This was extreme in the first 1,000 feet of the watercourse; in this section the total width occupied by the watercourse and the extended banks was as great as 35 feet. One exception to this was in the section immediately below the mogha which is adjacent to a paved road. The farmers reported that it was common practice for persons needing soil for making local bricks, improving the texture in their vegetable gardens or other purposes, to come to this section and haul the sediment away. When asked whether they thought the sediment would all be hauled away from this section if we built a sediment trap here to take out most of the sediment, the farmers replied in the affirmative and were obviously enthused about this possibility. Consequently, a sediment trap section was designed and constructed in the first 150 feet of the watercourse. The watercourse was excavated to a depth of one foot below the bed of the cement mixing structure, and the bottom width was at least six feet. This gave an initial flow section at least three feet by six feet, or eighteen square feet. At a flow of 3 cusecs the average velocity will be 0.17 feet per second. In the rest of the watercourse the velocity was designed to be at least 0.5 feet per second; and consequently, most of the sediment which settles in the watercourse will be deposited in this sediment trap. A rough estimate of the amount of sediment accumulated along this watercourse and number of years it had been in use indicate that from 5,000 to 7,000 cubic feet of sediment have been settling in this watercourse per year. Since the trap has a maximum capacity of about 900 cubic feet, it will have to be cleaned out from seven to ten times per year. During the monsoon season when the sediment load in the canals is high, it may even require weekly cleaning.

Since there was still some question as to whether the amount of sediment taken out at the sediment trap would be utilized by the normal users, the possibilities of using this sediment to make low cost soil cement bricks was investigated. The normal recommendation for the proper soil for making these bricks is to have a soil which has approximately equal amounts of sand, silt and clay. The sediment cleaned from the watercourses is primarily silt and fine sand. However, experiments indicated that the bricks made of the sediment were appreciably stronger than those formed from the soil (Kemper and Akram, 1976). Because the sediment also is easier to prepare, sieve and mix than soil with appreciable clay content, there is considerable labor savings if sediment is used rather than soil. The cost of the cement used in these bricks is about 1/3 the cost of an equivalent volume of regular fired brick. The strength of the sediment blocks (even when wet) is within the range required for construction purposes. Because there is a need for low cost construction materials in these rural villages, the manufacture of soil cement bricks from sediment extracted from sediment traps appear to be a feasible means of beneficially disposing of that sediment.

8. <u>Control and Measurement of Water with Minimal Head Loss</u>

To avoid the borrowing and accompanying degradation of the watercourse involved in the construction of earthen dams, improved control structures were planned throughout the improved section. Since the watercourse was fairly flat over most of its sections, and there is always some head loss at the check structures, it was decided to space these as far apart as possible. Of course, each farmer would like to have the check structure immediately following his outlet from the watercourse so that he does not have to fill an extra section of the watercourse leading to a check structure which is placed further downstream. To avoid this objection a general agreement was reached with the farmers that when the improvement of the watercourse caused a farmer to fill extra sections of the watercourse that the irrigation schedule (waribundi) would be modified and that this farmer would be given time from the time of the farmer who no longer had to fill that portion of the watercourse.

In some sections of the watercourse it was essential to maintain all the head possible to reach certain high fields. The 20-inch diameter orifice turnouts (nakkas) are about as large as they can be made and still be opened by a "small" farmer when water pressure difference of a foot or more is pushing them against the seat. Consequently, it was not feasible to make larger orifices. However, since the head loss is proportional to the square of the amount of water flowing through an orifice, the installation of two of these orifices side-by-side allows a reduction of the head loss to ½ of its former value. This was done at several sections to reduce the head loss from 0.12 feet at the check structure to .03 feet at the check structure. There are undoubtedly better check structure arrangements that can be designed. However, a double orifice does offer the alternative of leaving one of the orifices closed and being able to measure the appreciable head loss at the remaining orifice with a differential manometer, and estimating the flow at that point from the head loss which is measured. This eliminates the necessity of installing flumes in the watercourse to measure such flow. The temporary installation of such flumes is often an appreciable factor in degradation of watercourses where measurements are being taken. When these measurements do not need to be made, the other orifice can be opened and the head loss reduced to ¼ of that value.

9. <u>Culverts</u>

Observation of the original watercourse indicated that a large part of the degradation was due to animals and equipment crossing the watercourse to reach isolated fields. It was obvious that this degradation would continue unless culverts or bridges were installed which would allow crossing without damage to the watercourse. An analysis of the cost of purchase of materials and installation indicated that concrete pipe which presently costs about the same number of rupees per lineal foot as its diameter in inches (that is a 20" diameter pipe will cost about Rs. 20 per linear foot today in Pakistan) is the least expensive method for building such passageways. However, these culverts also have a head loss approximately equal to the head loss through an orifice of the same diameter and must be taken into consideration in the design of the watercourse. It was noted in the process of construction of rip rap entrances to and exits from these culverts and orifice structures that when the entrances and exits were funneled rather than having abrupt changes from the full watercourse cross section to the much smaller orifice or culvert cross section, the head losses were appreciably reduced. This has been noted previously in hydraulics literature; we are currently making measurements to determine whether this reduction in head loss is sufficiently great to warrant the extra cost involved in creating such funneled approaches and exits.

10. Erosion Control

Over the years the accumulation of sediment in the upper sections of the watercourse and its deposition on the banks has resulted in the banks being composed primarily of silt and fine sand. The permeability of this material is not excessively great, but it is highly erodible. Wherever there is appreciable head loss at a structure the turbulence, particularly behind the structure, causes appreciable erosion for a distance of five to seven feet.

In branch watercourses where the water runs only about one day a week, this erosion can be prevented economically by sodding the banks in the section to about seven feet below the structure. However, in the main watercourse where the water is running for six or seven days a week, grass will not survive and other forms of erosion protection such as brick-bat rip rap are necessary for about the same distance.

11. Animal Watering and Bathing Stations

The farmers were insistent that there be locations on the watercourse where buffalo could be watered and bathed. It was apparent that there were at least 50 points along the watercourse where major degradation had taken place as a result of these animal activities. The farmers proposed that if we would build four centralized bathing and watering stations (buffalo baths), they could convince the farmers to take their animals to the buffalo baths and prevent the general degradation of the watercourse which would otherwise occur. Consequently, buffalo baths of the types indicated in Figures 5B and 7 were constructed. In general these consisted of 9-inch thick walls around the periphery of the bath, with two ramps allowing access for the buffalo into the baths.

12. The Need for Farmers to Continue the Improvement through Their Sub-Branches to the Field

At first it was assumed that if the operating level of the water in the old sub-branches at the junctions with the main branches could be provided with 0.5 feet of free

Figure 7. Round buffalo bath before final excavation.

board, water could be satisfactorily carried to all the fields. These preliminary criteria were used partially because the topographic survey had not been completed. However, further considerations and some observations indicated that the flow in the main branches is increased significantly by the improvement; consequently, more head is required to push this increased flow through the sub-branches to the fields.

The degree to which these sub-branches are to be cleaned and enlarged becomes a factor in the design of the main channel and major branches. Even when a more objective criteria of 0.3 feet of head loss per 1,000 feet is accepted and built into the design, there are few of the farmers' sub-branches which have sufficient cross section or are sufficiently clean to carry the increased supply of water. The farmers have two acceptable alternatives: (1) split their water and use two sub-branches to carry the larger water supply; or (2) enlarge their sub-branches and keep them sufficiently clean to deliver the water to the fields without causing overtopping of their own sub-branch banks or back-up of water into the main branch causing overtopping there. The farmers of this watercourse elected to increase the size of their watercourses because they had experienced the larger water supply, were impressed with how fast the water could be pushed across the fields to give them "more uniform opportunity for intake time," and were willing to give up the land for enlarged watercourses rather than lose the advantage of working with a larger stream of water.

B. Schedule, Inputs and Costs

The original timetable called for farmers to improve approximately 30,000 feet in two months. The farmers were able to complete 30,000 feet in 48 days or an average of 625 feet per day. Allowing time for touch-up and finishing work they were under the original schedule by 4-5 days. The farmers provided a total of over 8,800 hours labor with a maximum 271 hours/day from 43 men. Including hired laborers and skilled masons the total program required over 13,000 hours of labor. The bulk of the physical construction work was finished in 60 days after the project began, but the installation of improved sections and cement nakkas, culverts and buffalo baths took another 40 days to complete. The buffalo baths required an average of over 100 hours each of masons' time - partly because each was an experimental installation and many details had to be worked out at site.

Table 12. Labor Units and Costs.

Category	No. of Hours	Rs/Unit	Total (Rs)
Volunteer farm labor[1]	8803	1 Rs/Hr	8803
WAPDA beldars	2572	1 Rs/Hr	2572
Skilled masons	1679	12.6 Rs/day	3526
Tractor Operator	148	1.5 Rs/Hr	222
Agricultural Engineers	780	6.5 Rs/Hr	5070
Supervisors[2]	2587 x 20%	10 Rs/Hr	5174
	x 80%	3 Rs/Hr	6208

[1]Opportunity cost charged for farm labor.

[2]The supervisory hours are broken out into Mohsin Wahla's time and rest of his field staffs' time. Much of the latter can be eliminated for the next project.

In addition to labor costs, the main expenditures were for control structures, buffalo baths and lined-canal sections. The understanding on the watercourse was that the capital inputs would be provided free if the farmers provided the labor and facilities to move, store, and install materials. Table 13 details the capital and tractor inputs required for the program.

Table 13. Capital Costs.

Category	No. of Units	Unit Costs (Rs/Unit)	Total (Rs.).
Tractor Hours	100 hours	39.5 Rs/Hr	3950
Cement	176 bags	22 Rs/bag	3850
Nakkas	95	50 Rs.	4750
Sand	816 cft.	180 Rs/truck	1170
Aggregate	125 cft.	325 Rs/truck	325
Bricks	61,000	230 Rs/1000	14030
			Rs 28075

Eliminating some of the mistakes and the lined buffalo baths would reduce the capital cost by perhaps as much as Rs. 15,000. Even so an improved earthen watercourse would cost the farmers about Rs. 22 in capital inputs per acre served or about Rs 0.67 in capital inputs per foot of improved watercourse. The total costs for the project was Rs. 59,650 or about Rs. 2 per foot of improved watercourse. With more practice and experience it is likely that the costs of such a project can be reduced to less than Rs. 1.5 per foot.

BENEFITS TO FARMERS

Increased Water Supply

An important criteria in evaluating watercourse renovation is the measurement of water conveyance loss.[1] While several procedures for loss measurements are feasible, the most convenient is the inflow-outflow method using Cutthroat flumes. Here, two or more flumes are installed in the channel separated by a distance of 1,000 feet or more; this minimum distance as specified to assure measurable loss. The loss is equal to the discharge difference between successive flumes. Such losses can be expressed in several ways; i.e. delivery efficiency, cusecs lost, cusecs lost per feet^2 of wetted perimeter, cusecs loss per 1,000 feet of channel and percent loss per 1,000 feet of channel. The latter expresses the loss in cusecs per cusec of initial flow, per 1,000 feet and recognizes the dependence of loss on both flow rate and distance.

Measurements of water losses taken before improvement provide the justification for watercourse renovation. Measurements taken after improvement (compared to those taken before) determine the benefits to the farmer in terms of increased water delivery to his fields.

1. Methods of Analysis

In analyzing the "before" and "after" losses, attempts were made to compare measurements of the same initial flow

[1] Loss as used herein includes both seepage and wastage.

rate over identical distances through all parts of the watercourse. In most instances such identical comparisons were not possible.

The second and most used comparative approach was developing predictive equations describing the "before" and "after" flow rates, or loss rates as function of distance or initial flow rate. Attempts were then made to solve these flow rate or loss rate distance equations for a particular distance and make the appropriate loss comparisons. In cases where there existed, for a particular distance, sufficient loss measurements of varying initial flow rates the derived loss-initial flow rate equations were solved for a common initial flow rate and loss comparisons made. These equations were derived using regression techniques. Where data were insufficient for equation derivation, comparisons were made on the basis of percent loss/1,000 feet and delivery efficiencies.

2. Water Losses Prior to Improvement

The "before" loss measurements are shown in Table 14. These data were acquired over a limited range of initial flow rates. The authorized mogha flow is 2.75 cusecs, but actual flow from the canal was generally less due to backing up of water in the watercourse. All measurements but one were made under tubewell supplemented conditions. Variation in the initial flow rates resulted from variations in the distributary operational level and variations in the fraction of tubewell water directed to an adjacent watercourse.

Table 14. Watercourse Losses for TW 56 Before Improvements.

No.	Date	Initial	Final	Loss	Distance	Loss	%Loss 1000 ft	Ed
		(cusecs)			(ft)	(cusec/1000)		%
1	19 Nov. 75	4.40	3.90	0.5	3,640	0.14	3.12	89
2	20 Nov. 75	4.80	4.20	0.6	3,860	0.16	3.24	88
		Main + A						
3	18 Nov. 75	4.60	2.45	2.15	2,440	0.88	19.16	53
4	18 Nov. 75	4.60	3.19	1.41	2,080	0.68	14.74	69
5	18 Nov. 75	4.60	2.50	2.10	4,270	0.49	10.69	54
		Main + C						
6	15 Nov. 75	4.48	2.24	2.24	9,340	0.24	5.35	50
7	15 Nov. 75	4.48	1.40	3.08	9,840	0.31	6.99	31
		Branch C						
8	20 Nov. 75	4.20	2.70	1.5	5,400	0.27	6.52	64
9	20 Nov. 75	4.20	2.97	1.23	3,680	0.33	7.96	71
10	19 Nov. 75	3.40	2.20	1.20	2,580	0.47	13.68	65
11	19 Nov. 75	3.40	2.60	0.80	1,340	0.80	17.56	75
12	20 Nov. 75	4.20	1.75	2.45	6,290	0.39	9.27	42
		Main + G						
13	17 Nov. 75	1.83	0.64	1.24	11,300	0.11	5.84	34
		Main + C + D + E + F						
14	15 Nov. 75	4.48	1.31	3.17	9,140	0.35	7.74	29
15	15 Nov. 75	4.48	2.65	1.83	9,140	0.20	4.47	59
16	15 Nov. 75	4.48	2.65	1.83	9,340	0.20	4.37	59
17	15 Nov. 75	4.48	2.30	2.18	9,840	0.22	4.95	51
18	15 Nov. 75	4.48	0.90	3.58	10,340	0.35	7.73	20

From the data of Table 14 the main channel was obviously an efficient water conveyor. Delivery efficiencies were 88-89 percent; and losses/1,000 feet were 3.12 percent to 3.24 percent. Although the initial flow rates were moderately high (4.4 and 4.8 cusecs) the delivery efficiencies and percent loss/1,000 feet were respectively the highest and lowest of all "before" measurements. The excellent performance of this main channel was probably due to the almost continuous flow of water which kept the channel both saturated and sealed. Rodents and insects do not deliberately dig holes into saturated soil or into a full watercourse. However, when water is not in a branch for several days the banks desaturate, burrowing conditions become ideal and many holes appear on inside faces of the banks.

When approximately the same initial flow, 4.60 cusecs, was diverted to Branch A (which connects with the main channel, 1,100 feet below the mogha) delivery efficiencies decreased 20 to 36 percent and percent loss/1,000 feet increased 7 to 15.5 percent even though two of the Main + A measurements were made over much shorter distances. This again exemplifies the possible difference between relatively continuous flow and transient flow channels. With the latter the alternate wetting and drying is more conducive to establishment of plant, insect, and rodent populations which result in a more porous bank. The drying during the non-flow periods also promotes seepage loss by the shrinking and cracking of silt films and wet soils that may have been used to block unimproved nakkas, dams, and so forth.

Farmers at the tails of the watercourse receive much less than their full allotment due to conveyance losses. At the end of Branch F, a distance of 10,000 feet from the mogha, only an average of 44 percent of an initial 4.88 cusec flow was delivered. At the end of Branch, (No. 2+12, 6,7. Table 14) only 39 percent of about 4.6 cusecs initial flow reached about 10,000 feet distance. Similarly at the end of Branch G, for a mogha discharge of 1.88 cusecs and a distance of 11,300 feet only 34 percent of the water was delivered. These low delivery efficiencies were the primary justification for watercourse renovation.

One general observation from the "before" data of Table 14 is that for a particular initial flow rate, delivery efficiencies decrease while loss and percent loss/1,000 feet increases going from the main channel out through the various branches. The "before" data are not sufficiently extensive to establish exact relations between distance or flow rate and loss, or percent loss/1,000 feet. However, from the Main through most branches, it implies a general relationship of the form $Y = a e^{bx}$ where b is positive or negative according to the dependent variable.

3. Water Losses Following Improvements

After completion of watercourse rehabilitation, conveyance losses were measured to determine the improvement in water delivery (Table 15). These losses were measured under a greater range of mogha discharge rates because of greater variations in distributary operating levels. In addition, measurements were made with the tubewell both on and off.

To determine easily the decrease in water loss due to improvements, "before" and "after" comparisons should be made at the same mogha discharge rates and over the same distance. As shown by Kemper et al. (1975a), the greatest loss is through the upper bank portion; these sections are more porous because of greater plant, insect, and rodent populations. Obviously, for a given channel cross section the greater the initial flow rate, the greater the water depth, and thus the greater the rate of loss.

Figure 8 shows the "after" relationship between loss (cusecs) at a distance 3,980 feet in the main channel and discharge at the upper flume. The best fitting equation to the data points of Table 15 (measurements #2, 3, 4, 5, 7, 8, 9, 10, and 11) is:

$$\text{Loss (cusec)} = 0.00946\ e^{0.852Q}$$

Where Q = mogha flow in cusecs

$$r^2 = 0.9674 \qquad (1)$$

$$\%\ \text{Loss/1,000 ft} = 0.182\ e^{0.590Q}$$

$$r^2 = 0.9380 \qquad (2)$$

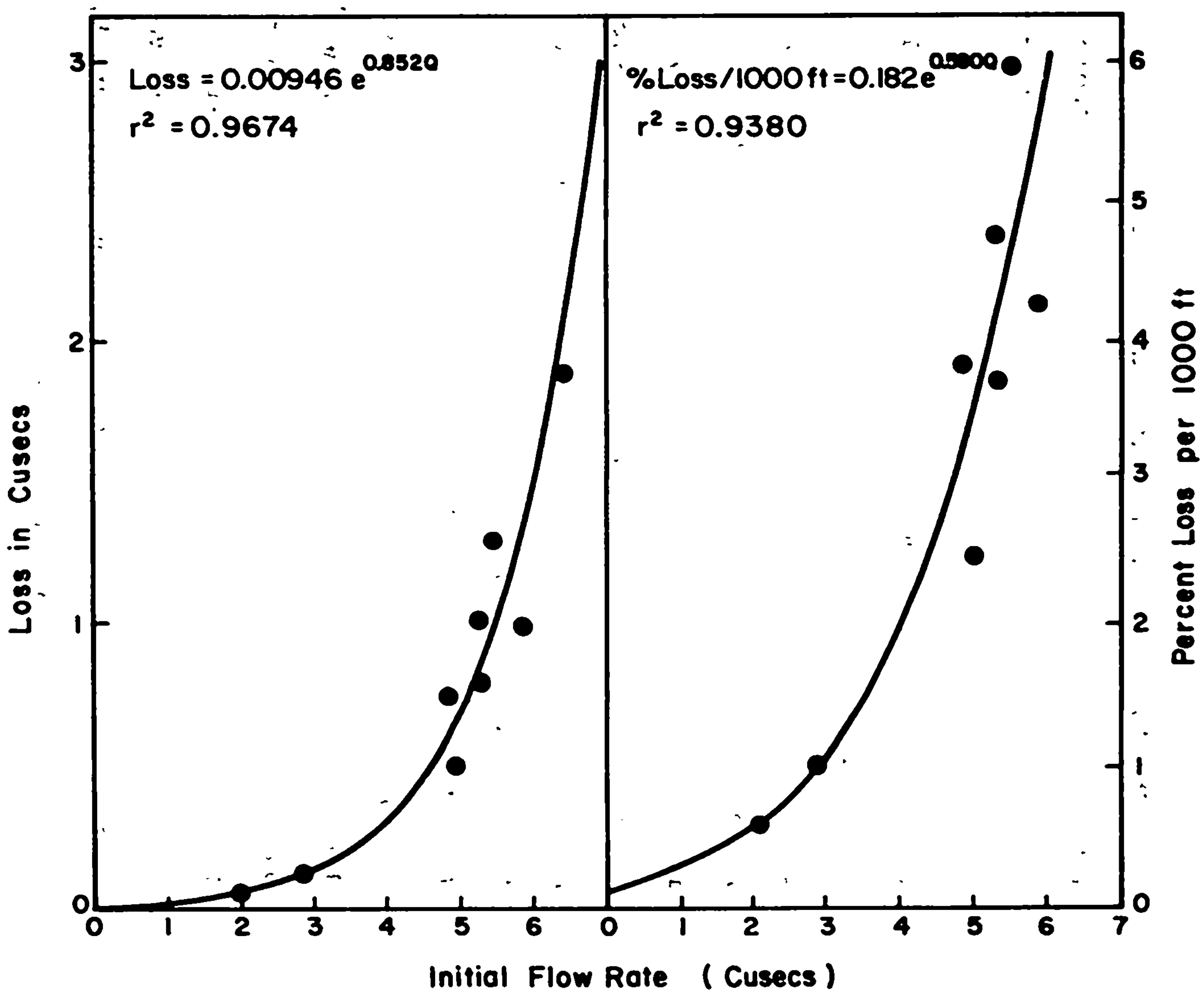

Figure 8. Curves Depicting the "After" Relationship between Loss (cusecs) and Initial Flow Rate and Percent Loss/1,000 Feet and Initial Flow Rate for a Distance of 3980 in the Main Channel.

Equation (2) is also plotted in Figure 8. One point 7.69 percent (#2, Table 15) was beyond the upper limit of the graph.

The "after" measurement taken on March 27, 1976 (No. 11, Table 15) is the most logical single choice for main channel improvement evaluation. Both the flow rate and distance approximate the "before" measurements (No. 2, Table 14) made on November 20, 1975. The delivery efficiency, 84.5 percent and the percent loss/1,000 feet, 3.89 percent, differ little from the "before" value. For initial flow rates up to 4.80 cusecs renovation did not improve water conveyance in the main channel. However, the overtopping before renovation, caused by occasional high flows, was eliminated by the improvement which included 1.0 feet of free board in this section.

(a) Main Channel and Branch A

For the Main channel plus Branch A there is no direct comparison of "before" and "after" measurement because both initial flow rates and measurement distances differ greatly. Nevertheless, even with greater initial flow rates, after renovation less water was lost over greater conveyance distances. According to Figure 8, losses for a particular distance should increase with greater initial flow rates. For an average "after" flow rate of 1.10 cusecs (Nos. 12 and 13, Table 15) the average loss over 3,300 feet was 1.12 cusecs, the delivery efficiency was 81.6 percent and percent loss/1,000 feet was 5.56 percent. Compare this with the "before" weighted average (average of Nos. 3, 4, and 5, Table 14) measurement where the initial flow rate was of 4.60 cusecs. The weighted average loss was 1.95 cusecs at a weighted average distance of 3,030 feet; delivery efficiency was 57.6 percent loss/1,000 feet was 14.7 percent.

From the limited data taken before improvement there is some indication that the decrease in flow rate with distance (i.e., the loss rate) is roughly proportional to the flow rate:

$$\frac{dQ}{dD} = K\,Q \qquad (3)$$

Fitting this linear relation to the above weighted data the following equation can be computed for the flow prior to improvement:

$$Q = 4.60\, e^{-0.000\,182\,(D)} \qquad (4)$$

Where Q = flow rate in cusecs

D = Distance in feet

When solved for a distance of 3,300 feet, the approximate "before" rate should be 2.52 cusecs resulting in a 2.08 cusec loss. Thus, comparing the extrapolated "before" loss at 3,300 feet with the "after" measured loss at 3,300 feet, the <u>minimum</u> improvement in conveyance from Main through Branch A could have been percent improvement[1] = (1-1.2/2.08) 100 = 46 percent. Minimum is here emphasized,

[1]Percent improvement is the percent by which the loss decreased after watercourse improvement.

since from the trend shown in Figure 8, had the "after" flow rate been only 4.6 (the same as the "before" rate) instead of 6.10 cusecs, the expected loss would have been less than 1.12 cusecs. Consequently, 46 percent must be considered as a conservative estimate of the decrease in water loss. The correctness of the above answer depends on the validity of the linearity assumption in Equation (3).

General observations of data presented in this paper supports this assumption.

(b) Main Channel + Branch C

"Before" and "after" measurements on Main plus Branch C are also not directly comparable since their flow rates and loss distances also differed greatly. Therefore, a loss equation was derived for the "before" condition on the Main + Branch C. Using regression techniques on measurement No.'s 1, 2, 6, 7, 2 + 9, and 2 + 12 (Table 14) the following loss equation was derived:

$$\text{Loss (cusecs)} = 0.2036\, e^{0.000270\,(\text{Distance in feet})} \quad \text{Where } r^2 = 0.984 \qquad (5)$$

In the above measurements flow rates varied from 4.4 to 4.8 cusecs with a mean of 4.65; these differences were ignored and considered part of the errors involved. Obviously, the equation overestimates loss in the vicinity of the upper flume but is reasonably correct at other distances.

From Equation (5a) "before" loss of 2.64 cusecs was calculated for a distance of 9,480 feet. From Table 15, "after" measurements Nos. 17, 19, and 20 give the cusecs lost over 9,480 feet for initial flow rates of 2.0, 6.15, and 5.85 cusecs. Again using regression techniques, the following equation relating initial flow rate and loss at a distance of 9,480 feet was derived:

$$\text{Loss (cusecs)} = 0.290\ e^{0.379Q} \qquad (6)$$

Where Q = flow rate in cusecs

$r^2 = 0.9998$

Equation (6) was solved for the loss at a flow rate of 4.65 cusecs, the mean of the "before" flow rates used in the derivation of Equation (5). The calculated "after" loss was 1.69 cusecs at 9,480 feet. Thus, by the use of these "before" and "after" loss equations the improvement in conveyance loss for 4.65 cusecs at 9,480 feet was the following:

$$\%\ \text{improvement} = \left(1 - \frac{1.69}{2.64}\right) 100 = 36.0\%$$

(c) Main Channel + Branches C, D, E, and F

Again because of non-comparable flow rates and distances, water conveyance improvement could not be determined directly for Main + C + D + E + F Branches. A loss equation was derived again for "before" measurement and compared with the one "after" measurement. Using the appropriate measurements (Nos. 1, 2, 14, 15, 16, 17 and 18 of Table 14) and regression techniques the following loss-distance equation was derived:

$$\text{Loss (cusecs)} = 0.2074\ e^{0.000257\ (\text{Distance in ft})} \qquad (7)$$
$$r^2 = 0.9165$$

In calculating Equation (7), all flow rates, which varied from 4.4 to 4.8 cusecs, (mean 4.51) were considered of the same value. The derived Equation (7) when solved for a distance of 7,480 feet showed a 1.42 cusec loss.

The "after" measurement (No. 29, Table 15) was for a 7,480 feet distance. This site was along the channel for which Equation (7) was established. Thus at 7,480 feet from the mogha the loss "before" construction was 1.42 cusecs with an average initial flow rate of 4.51 cusecs. The "after" loss was 1.83 cusecs with an initial flow rate of 6.13 cusecs. Because of this initial flow rate difference, it is difficult to make a quantitative determination of the improvement due to renovation. From the loss-flow rate trend of the main channel (Figure 8) for a particular distance a 6.13 cusecs flow should show greater loss than a 4.51 cusecs flow. Had the "after" flow been 4.51 cusecs, it is certain the loss would be less than 1.83 cusecs and probably less than the 1.42 cusec "before" loss.

Since the data cannot establish the exact conveyance improvement at a 7,480 feet distance, the next most meaningful comparison is percent loss/1,000 ft; the "after" loss was 3.99 percent/1,000 feet.

(d) Main Channel + Branch G

The improvement on the Main through Branch G was equally hard to establish. Again the "before" and "after" loss measurements differ greatly in their initial flow rates and differ moderately in distances. In addition the "before" data were not sufficient to establish loss-distance relationship. On the basis of percent loss/ 1,000 feet the "before" measurement showed 5.84 percent (No. 13, Table 14) for a 1.88 cusec initial flow and a 11,300 feet distance. The "after" measurements (Nos. 32-36, Table 15) averaged a 3.24 percent loss/ 1,000 feet for an average initial flow rate of 5.37 cusecs. The average conveyance distance was 8,648 feet.

(e) Overall Improvement

The increase in supply and different lengths of watercourse considered do not allow strictly valid one parameter comparisons. However, arithmetic averages, with recognition of their deficiency, of the "before" (Nos. 3-7, 2 + 9, 2 + 12, 13-18, Table 14) and "after" (Nos. 12 to 14, 16 to 20, 24 to 27, 29, 31 to 35, Table 15) are presented in Table 16 as an indication of the improvement. The averages show the "before" delivery efficiency at 8,058 feet was 47.5 percent; the "after" delivery efficiency at 7,300 feet was 70.7 percent.

Table 15. After Renovation Water Loss Measurements on Tubewell 56.

No.	Date	Initial (cusecs)	Final (cusecs)	Loss (cusecs)	Distance (ft)	Loss (cusec/1000)	% Loss 1000 ft	Ed %
				Main				
1	2-6-76	2.55	2.25	0.25	2200	0.11	5.36	88.2
2	2-18-76	6.20	4.30	1.90	3980	0.48	7.69	69.4
3	2-19-76	2.92	2.80	0.12	3900	0.03	1.03	95.9
4	2-21-76	5.45	4.15	1.30	3980	0.33	6.01	76.1
5	2-23-76	5.30	4.50	0.80	3980	0.20	3.79	84.9
6	2-26-76	2.60	2.55	0.05	1100	0.05	1.73	98.1
7	3-8-76	5.85	4.85	1.00	3900	0.25	4.30	82.9
8	3-10-76	5.30	4.28	1.02	3980	0.26	4.82	80.8
9	3-22-76	2.05	2.00	0.05	3980	0.01	0.60	97.6
10	3-24-76	5.00	4.50	0.50	3980	0.13	2.51	90.0
11	3-27-76	4.85	4.10	0.75	3980	0.19	3.89	84.5
				MAIN + A				
12	2-10-76	6.50	5.37	1.13	3300	0.34	5.27	82.6
13	2-24-76	5.70	4.60	1.10	3300	0.33	5.85	80.7
14	2-26-76	2.60	2.00	0.60	4400	0.14	5.25	76.9
				A				
15	2-26-76	2.55	2.00	0.55	3300	0.17	5.25	76.9
				MAIN + C				
16	2-4-76	2.97	1.95	1.02	6180	0.16	5.50	66.6
17	2-5-76	2.00	1.84	0.62	9480	0.07	3.27	67.0
18	2-20-76	5.73	4.95	0.78	6180	0.13	2.20	86.4
19	3-4-76	6.15	3.19	2.96	9480	0.31	5.07	51.9
20	3-8-76	5.85	3.15	2.70	9480	0.27	4.86	53.8
				C				
21	3-4-76	5.23	3.19	2.04	5500	0.37	7.09	61.0
22	3-8-76	4.85	3.15	1.70	5500	0.31	6.37	64.9
23	3-18-76	4.76	4.09	0.66	5250	0.13	2.64	86.1
				MAIN + C + D				
24	2-13-76	6.65	4.35	2.30	8380	0.27	4.13	65.4
25	2-20-76	5.73	4.10	1.63	6180	0.26	4.66	71.2
26	2-26-76	4.75	3.20	1.55	6980	0.22	4.68	67.4
27	2-27-76	4.85	4.00	0.85	7280	0.12	2.40	82.5
				BRANCH D				
28	2-20-76	4.95	4.10	0.85	1100	0.77	15.6	82.8
				MAIN + C + D + E				
29	3-6-76	6.13	4.30	1.83	7480	0.24	4.00	70.1
				E				
30	3-6-76	4.30	3.25	1.05	--	--	--	75.6
				MAIN + G				
31	2-7-76	5.50	3.45	2.05	9480	0.22	3.93	62.7
32	2-16-76	6.60	4.15	2.45	9480	0.26	3.91	62.9
33	2-23-76	5.30	4.15	1.15	9480	0.12	2.29	78.3
34	3-19-76	4.73	4.22	0.51	5000	0.10	2.16	89.2
35	3-19-76	4.73	2.91	1.82	9800	0.19	3.92	61.5
				BRANCH G				
36	2-23-76	4.50	4.15	0.13	2200	0.16	3.55	92.2

Table 16. Average Supply to the Watercourse, Delivery to the Field, and Delivery Efficiency and after Improvement at TW 56.

	Supply to WC (cusecs)	Delivery to Fields (secs)	Ed%	Avg. Flow Measurement Distance
Before	4.36	2.07	47.5	8058
After	5.14	3.63	70.6	7300

4. Recognition by Farmers of Improvement

An important criteria in judging the improvement due to watercourse renovation is how the farmers view it. Farmers readily acknowledge at least two benefits: (1) the greater ease in control of water by use of improved nakkas and check structures; and (2) the increased quantity of water. Most farmers, as reported by the Senior Extension Officer at Mona, believe the water supply has doubled. Mr. Malik Nawaz, based on the time required to irrigate a particular area reports a 63 percent increase in the water available at the end of Branch G.

5. Potential for Further Increase

Nearing completion of the watercourse improvement an attempt was made to seal all rodent and other holes within the various channels. Unfortunately, the holes were not properly plugged in many sections and are contributing to loss after improvement. The complete sealing of these holes should result in additional loss reduction.

A further increase in irrigation water delivery to fields could be affected by improving and cleaning the channels within the farmers fields. While farmers channels are subject to the same types of loss existing in the branches, they are generally not as well maintained. In addition, poorly cleaned farmer channels tend to increase water levels in the branch channels leading to generally greater seepage and frequent overtopping.

B. Other Benefits

1. Reduction of Seepage Damage

Seepage damage to the crops was practically eliminated (and will remain negligible if the farmers will develop and adequate cleaning and maintenance program). There was not as much seepage damage along the watercourse surveyed in this as in other areas; however, a walking survey indicated that about 50 percent of the trees in the first row next to the watercourses had been stunted compared to trees further away from the watercourse. Yield from these stunted trees was about 50 percent less than the yield of normal trees. Because there were citrus trees on one side or the other of about 12,000 feet of this watercourse, it is estimated that about 300 trees were damaged by seepage. Yield reduction on these trees would be equivalent to the yield of about 1.35 acres of citrus. Since these citrus gardens were returning about Rs. 6,000 per year, the seepage damage to the citrus is estimated at about Rs. 8,000 per year. The total damage to all other crops probably was less than Rs. 13,000 per year.

2. Keeping Sediment Out of the Farmlands

The rates of accumulation of sediment in the sediment traps have been approximately as predicted. The farmers and the watercourse watchman (Khal Chowkidar) need to be instructed more completely on when to clean the sediment from this trap, because on at least ono occasion they have allowed it to fill up accumulating appreciable sediment in the watercourse. As long as the trap was kept clean there was practically negligible accumulation of sediment in the downstream sections. Assuming that the farmers did clean this trap at the proper intervals and took all 7,000 cubic feet of sediment out of the trap, the farmers would be saved the cost of moving this 260 cubic yards of sediment away from the banks and releveling their land. Assuming that this cost is about that charged for land leveling (that is, Rs. 3 per cubic yard) the annual savings to the farmer would be about Rs. 800.

3. Labor Savings at Junctions

The labor savings at the junctions from installation of the improved nakkas can only be estimated from a few time and motion studies taken on watercourses which were carrying approximately the same amount of water. In these few observations, it required 10 cubic feet of earth to properly and safely stop a water flow of 5 cusecs. When these dams were removed and if the farmer were conscientious about trying to get all of the soil back out of the water-course, at least 20 percent of the earth was still lost by erosion. The erosion resulted in these borrow pits along side such dams growing at the rate of two cubic feet per week or about four cubic yards per year. Replacement of this soil from the fields at a rate of Rs. 3 per cubic yard would cost the farmer about Rs. 12 per year per dam. Farmers working steadily throughout the day have been monitored moving about 18 cubic feet of earth per hour over equivalent distances; consequently, the farmer who fills and moves a dam has probably spent about the same amount of energy. The farmer does not actually spend 30 minutes closing a dam on a 5-cusec watercourse. One or two work as fast as they can as the water keeps washing away the soil and usually manage to close a gap with a few large pieces of sod fill soil. The struggle may take only 5 to 15 minutes depending on the number of men and the stream size. However, at the end of this time they are generally ready for a 10 or 20-minute rest. Farmers also will find many ways to reduce the amount of soil in a dam. Keeping the dam very narrow and reducing the free board to practically zero are among these ways, in spite of the fact that this results in an appreciable wash-out rate and accounts for an appreciable amount of the operational losses described earlier. In general, the farmer can properly open and close an improved nakka in less than 10 minutes, including the time he spends packing mud into the groove on the present orifice panels. At this rate he expends about 8 hours per year and his savings in labor amounts to about 40 hours per year per improved nakka installed. This labor saving plus the eliminated need of hauling earth from the fields to the borrow pits can amortize the cost of the Rs. 200/nakka in 5 to 10 years depending on the cost of the labor and the interest rate of the borrowed money.

4. Control and Measurement of the Water

Other benefits due to the improvements may develop. For instance, if an irrigation advisory service to the farmers is made available to help them apply the proper amount of water to their crops, it will be essential that the amount of water be either measured frequently or be sufficiently constant that the farmer will know how many minutes to let it run to apply a certain number of acre inches to his field. If the farmers will maintain their watercourses and clean them regularly so the water levels and loss rates do not rise appreciably, the rate of delivery will be reasonably constant. Studies by Mr. Bashir Ahmed and Dr. S. A. Bowers also indicate that the rate of flow through these orifice nakkas can be calibrated against the head loss and then the measured head loss can give a reasonable estimate of the amount of water flowing through the orifice and thereby provide the farmer with the needed information as to flow rate. It is probable that this measurement will have to be done by some reasonably trained person to begin with, such as the field assistant or the tubewell operator.

Another benefit of having permanent measurement structures in the watercourse is the rates of water loss are much more easily measured. Cleaning and maintenance scheduling also can be based on such measurement rather than on the subjective will of 30 or 40 farmers.

WATERCOURSE MAINTENANCE

A. Hiring of Khal Chowkidor and His Assignments

Organization of a watercourse maintenance program is deemed necessary to assure an adequate water supply to all watercourse farmers. An important part of the program is the Khal Chowkidar. In general, his duties are to patrol the watercourse and repair all obvious sources, or potential sources, of water loss such as seepage through banks, nakkas, rodent holes, overtopping, etc. Similarly he reports to the watercourse committee all violations of watercourse regulations, including theft of water, damage to the watercourse, etc.

This Khal Chowkidar, in addition, acts as intermediary between the farmers and the watercourse committee. He reports on requests and informs farmers of committee decisions and rulings.

The watercourse committee has hired the Khal Chowkidar, Mr. Mohammad Manak, for 32 maunds of wheat per year (R. 1200/ year). He is also authorized (informally) to graze his two buffalo along certain sections of the watercourse and to cut grass along other sections. Mr. Manak, after receiving instruction in the recognition and remedy for sources of water loss, has assumed the Khal Chowkidar duties.

B. Schedule and Procedure of Maintenance and Cleaning Program

One of the duties assigned to the Khal Chowkidar is scheduling maintenance and cleaning and directing the work party. He schedules: the maintenance and cleaning of the watercourse when the tubewell supplemented water level reaches a particular height. A gage indicating the water level has been installed along with permanent measurement structures. The relation of loss to height of water in the watercourse is being determined. This data will be presented to the users executive committee who will decide the height to which the water level should be allowed to rise before cleaning. In general, all watercourse subscribers will contribute to the cleaning and maintenance of the main channel. However, branches A, B, C-F and G, will be cleaned and maintained by only the farmers served by these particular sections. Any farmer failing to contribute his just share to cleaning and maintenance operations will be subject to penalty on decision of the watercourse committee.

C. Cleaning the Sediment Trap

The sediment trap is supposed to be cleaned anytime after it is half full and before it is full in order to prevent filling of the trap and deposit of sediment in the downstream sections. All farmers will be equally responsible for this cleaning and will assume this responsibility on a rotation basis assigned by the Khal Chowkidar.

D. Estimated Maintenance Cost of Improved Structure

At most points where the check structure and improved nakkas are installed together one nakka lid will be surplus. The Kahl Chowkidar will store these excess lids as replacements for lids that may be damaged in the future. Where a farmer has installed gaskets on the lids, the Khal Chowkidar will inspect the gaskets periodically. If replacement is required, it will be his responsibility to do so. Foam rubber gasket material costs Rs. 0.50/feet; the estimated cost of gasket replacements, including rubber cement on a 20-inch lid is Rs. 3. It is doubtful that the nakka panels will require replacement. However, if necessary new panels with lids, 20 inches in diameter, may be purchased for Rs. 60 each.

ECONOMIC ANALYSIS

A. Improvements and Maintenance Costs

Since this type of improvement has not been in place anywhere for more than a few months, estimates of the life of the materials are just that, . estimate. For the earthen-improved watercourse with proper maintenance there is no physical reason why the farmers should be required to go through such an all-out effort again. As long as the farmers do not let the banks erode and keep the channel clean and desilted, they should have good service from their channel. The lined sections, buffalo baths, and cement nakkas all are damageable if mistreated. The lined sections with 9-inch walls should have an average life of at least 12 years, while the sections of the buffalo baths may last only 10 years due to the heavy use. Prompt repair of any problems and maintenance to replace cracked or broken portions will, of course, increase the above figures.

On the average the farmers should plan to invest about one hour per year in cleaning and maintenance on each 10 feet of watercourse and be prepared to replace 20 percent of the panel nakka lids (@ Rs. 20) and 10 percent of the panels (@ Rs. 60) each year. The work of the khal chowkidar will increase the effectiveness of the farmer's maintenance work and will serve to identify trouble spots before they become major. The annual costs for watercourse maintenance and improvements, including the khal chowdikar at TW 56 watercourse, will be about Rs. 2800 plus Rs. 3000 opportunity costs for labor. With approximately 2800 acre-feet entering the watercourse at the head annually (canal water plus SCARP tubewell water) the cleaning and maintenance costs add only about one rupee of capital and one rupee's worth of labor to the cost of an acre-foot of water.

B. **Benefits**

The farmers on the watercourse, especially those with land near the tail of the watercourse already recognize that they are receiving additional water. Conversion of this additional water into economic benefits will be achieved as it replaces gasoline-powered private tubewell pumped water; as it is used to increase cropping intensity (acres cultivated), as it is used to increase stands (and consequently yields); and/or as it is used to grow high value crops with high water demand. If the farmers do not use this water properly, it will provide no economic benefits and may in fact, cause some economic losses as a result of nitrate leaching and water-logging at the tail end. The obvious answer is an extensive effort to educate the farmers in proper irrigation practices and crop water needs (see Extension Activities).

The long-term benefits from the increased water will become apparent as the extension activities bear fruit. It is unreasonable to expect the farmers to increase immediately their cropping intensity, especially because the watercourse has a present cropping intensity of greater than 160%. However, the combination of increased water supply and higher support price for cotton in conjunction with the continuing high price for citrus should lead to a small increase during Kharif 1976. Until the long-term changes occur and are measured, the benefits attributable to the increased water can only be estimated using data from other sources. One measure of the value of the additional water is the cost of the next viable alternative source of water supply. In this area since the shallow groundwater (down to about 200 feet) is relatively good, the alternative source of water supply is from private or public tubewells. Table 17 presents the costs of water from tubewells and canals.

Table 17. Water costs.

Source	Cost at Source (Rs/AF)	Costs at Nakka (Rs/AF)	Source Cost Changes as Supply Increases
Canal Water (a)	10.0	10-30 (b)	Fixed cost per acre but supply is limited.
Private Tubewell	37.0	46.0	Per unit costs rapidly decrease - approach 20 Rs/AF.
Public Tubewell (Old)	24.0	48.0	
Public Tubewell (New)	48.0	96.0	Per unit cost decrease approach 20 Rs/AF

(a) Set rate per acre regardless of quantity delivered
(b) Costs vary depending upon yearly canal supply

Additional water delivered at the nakka from groundwater costs about Rs. 46 per acre foot. If we take this as the value of additional water provided by the project, and approximately 700 acre-feet of additional water are provided annually, then the benefits are of the order of Rs. 32,200 per year. However, because of the monsoon rains and the changes in crop water demands over time, only 75% of the year is this water required for the crops (even with 200% cropping intensity). Thus, the annual benefits are estimated at Rs. 24,150.

C. Benefit/Costs Analysis

Looking at the improvements on the watercourse over the life of the improved structures provided us with a comparison of the benefits to costs for such a project. The benefit/cost ratio is defined as the present worth of the benefits, PVB, divided by the present worth of the costs, PVC, where:

$$PVB = Bo + \frac{B_1}{(1+r)} + ---- + \frac{B_n}{(1+r)^n}$$

$$PVC = Co + \frac{C_1}{(1=r)} + ---- + \frac{C_n}{(1+r)^n}$$

Bo and Co; B_1 and C_1; etc. = benefits and costs per year 0; 1; 2; etc.; r = discount rate, 1, ---- N = number of years of the project life.

Using a life of 25 years, a value of water of Rs. 46; and a discount rate of 15%; the benefit/cost (B/C) ratio for the project is 1.76. With a discount rate of 10% and the same value of water and life; the B/B ratio is 2.42. Table 18 represents a range of B/C ratios based on different values of water and discount rates.

From this table it is apparent that as the farmers more effectively utilize their water, the increased value will lead to increased benefits and a higher B/C ratio. Removal of the research component, more efficient utilization of staff, or reduced social costs of capital leading to a lower discount rate will also yield an improved B/C ratio. Farmers on a nearby watercourse (TW 73) have observed the project and

Table 18. B/C ratios based on three values of water.

	B/C Ratios Discount Rate	
Value of Water	10%[d]	15%[e]
46 Rs/AF[a]	2.42	1.76
58 Rs/AF[b]	3.05	2.56
100 Rs/AF[c]	4.74	3.82

[a]Lease cost alternative source of water supply

[b]Shadow value for water for entire year in improved SCARP watercourse[1]

[c]Estimated cost of additional water supplied from Tarbela Dam

[d]Subsidized capital costs

[e]Costs for capital from commercial sources

are presently attempting to duplicate it on their own watercourse. This indicates that the farmers also believe there is a positive B/C ratio associated with this work.

D. National Scale

The potential for this type of project being implemented on a national scale is both exciting and frustrating. The potential benefits, in improved stands and increased yields and intensities are tremendous. In the present SCARP areas alone this type of project could save over 2 MAF of water which would not only provide additional irrigation water, but would also significantly reduce waterlogging and salinity. Improvement of the bulk of the watercourses in Pakistan would eliminate need to import grain, because it would provide sufficient irrigation water to reach self sufficiency.

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[1]Eckert, Jerry, et al, "Water Management in Irrigated Cropping Systems of Pakistan." CSU Progress Report, Colorado State University (November 1975).

The frustrating part of the problem is that with all of the educated personnel in Pakistan few have training in on-farm level agricultural engineering; therefore, the possibility of spreading the program to a national level is severely restricted by the manpower shortage. It is possible to establish specialized training centers to instruct farmers and field assistants; eventually this will be necessary. This present shortage, however, necessarily restricts improvement schemes to an area that can be serviced by the available manpower pool.

EXTENSION ACTIVITIES

The watercourse improvements at TW 56 and TW 78 provide an excellent opportunity for an extension program. The rapport and credibility that are so necessary to effective extension work have been established.

A. Irrigation Advisory Assistance

The major extension activity that has been carried out by the CSU field party on previously improved watercourses is land leveling. This activity will be continued but will be integrated into a more comprehensive program of Irrigation Advisory Assistance.

The initial advisory phases of this program are based on previous irrigation evaluations on the watercourse and on calculation of expected weekly irrigation demand for the major crops.

The irrigation evaluations have provided information about the present irrigation practices of a number of farmers.

Information is now available concerning average flow at the nakka, irrigation application efficiencies, and, to some extent, the farmers criteria for irrigation timing. Information is being collected about the present and proposed crops on these farms (initially 6 farms on TW 78 and 6 on TW 56). The expected water demand for these crops will be calculated and an irrigation schedule prepared. If expected water demand exceeds flow, or if expected flow greatly exceeds demand, suggestions will be made for changes in the proposed cropping patterns. Field staff will consult with the farmer weekly and help him decide on the best utilization of his weekly water turn, based on both the schedule and the actual soil moisture conditions in the field. The projected schedule will be periodically updated if abnormal rainfall or water use conditions, or if substantial deviations occur from any other cause.

If abnormal irrigation times are encountered due to uneven fields, land leveling will be recommended along with assistance in planning and carrying out the leveling operation and monitoring the effect on irrigation efficiency.

B. Crop Extension Program

In addition to the Irrigation Advisory Assistance which is planned to be conducted by the present staff, a crop by crop extension program is envisioned. This will require substantial effort and additional personnel if it is to be undertaken at more than a minimal level.

In this approach a list of essential practices and inputs would be developed.

These would differ somewhat from the standard list of improved practices. They would be highly specific, and only those practices and inputs absolutely necessary to an acceptable level of productivity would be included. The level of inputs will be maintained in order that a maximum benefit/cost ratio can be expected. The number of practices and recommendations for each crop shall be rigorously pruned in the interest of simplicity. These will be printed in Urdu, one sheet per crop, and distributed on the watercourse on a saturation basis. This will be followed by extension staff visitation to explain the recommendation and to assist the growers in attaining required inputs. The success of fields on which the recommendations are followed will be monitored to determine their effectiveness, and the recommendations will be re-evaluated seasonally. Problems encountered by the farmers will be identified and solved to the extent possible. It should be possible to develop simple, direct crop by crop improvement programs that can and will be adopted by the small farmer.

MISTAKES COMMITTED AND SUGGESTIONS TO AVOID OR CORRECT THEM IN THE FUTURE

A. Side Slopes and Alignment

At the location of the watercourse where this project was initiated the slope and flow rate were such that the design depth of water in a channel with 1:1 side slope needed to be only 18 inches and the free board required was 0.5 feet. Consequently, the horizontal distance involved from the edge of the bed to the inside shoulder of the bank was only 2 feet. The engineer in charge laid out the rest of that branch and most of the main watercourse using the criteria of 2 feet of horizontal distance from the edge of the bed of the watercourse to the inside shoulder. This gave approximately a 1:1 slope in the lower sections of the Branch G. When this same horizontal distance, however, was combined with the 2 feet of operating depth and 1 foot of free board designed in the upper portions of the main channel, the result was over 3 feet of vertical distance combined with only 2 feet of horizontal distance. The side slopes were much steeper than 1:1 which caused considerable slippage of soil back into the channel when banks were wetted. This occurred in those portions of the watercourse where the sides had been filled, and the soil material was sediment (which is primarily silt and fine sand) and had not been adequately compacted before the water was let back into the watercourse. This steeper than desired slope can be avoided by instructing the engineer to set his alignment with stakes down the middle of the watercourse and to measure his distances at each station from those center-marking poles. These must be measured according to the needs of horizontal distance to achieve the bottom width, horizontal distance in the side slope, top width of the bank and horizontal distance in the outside side slope according to design specifications.

B. Elevation of the Watercourse

One section of over 2,000 feet was constructed exactly 0.5 feet too low, in spite of a plan to check watercourse elevations by having the engineer in charge making independent elevation determinations to check the engineer who set the elevation of the watercourse. In general, the engineer setting the watercourse had made a recording error at a turning point and had failed to close his survey; therefore, he did not detect that error. The engineer in charge of setting the improved structures was in a hurry on that section and decided to just eyeball the structures into the existing watercourse bed rather than to set their elevations independently.

To some extent each of these engineers could blame the other for his mistake. In the future each person conducting a survey will be carefully appraised of his professional responsibility to make his elevations correct and check them by closing his survey. In the future permanent bench marks will be installed or located at the rate of about 1 per square. These bench marks will be surveyed to determine their exact elevation. The survey to determine the exact elevations of these bench marks will be closed, and copies of maps showing these bench marks and their elevations will be distributed to all persons responsible for determining and setting additional elevations on this improvement program.

C. <u>Compaction of Soils Around Structures</u>

In our enthusiasm to get water back into the watercourse as soon as possible, the soil around the improved structures was often compacted later in the same day or on the day following the construction of the structures. In several cases this broke the green mortar connecting the wing walls to the main structure and required repair. It was found that this breakage could be avoided if at least one day was allowed between the time of construction and the time of filling the soil in around the structures, and if the soil around the structures could be packed rather gently by foot pressure at that time, rather than pounding the soil with a metal compactor.

D. <u>Wing Walls and Position of Structures</u>

When the masons set these structures in the watercourses, they often attempted to get the bottom lip of the structure against the line representing the edge of a 2-foot bottom width. To reduce the hydraulic head loss at the circular orifice, these orifices were placed at an angle of 60 degrees with the horizontal rather than 45 degrees as was originally planned. Thus, the tops of these structures stuck out several inches from the banks constructed at a 1:1 slope. When the cutoff walls were built even with the top of the structures, the top of these cut-off walls also protruded out into the watercourse. This can be avoided by setting the structure back into the bank an extra foot so that the wing wall is approximately centered in the bank and becomes an integral part of the bank rather than a facing to the bank behind which the water can circulate, erode the soil and result in washouts.

When there is sufficient slope to the watercourse that the 1 to 2 hundredths of a foot head loss saved by having the panels at 60 degrees is not essential, installation of the panel containing the orifice at 45 degrees is recommended. It is also recommended that this panel be put in flush with the designed inside surface of the watercourse at 45 degrees, and that the whole masonry structure conform with the shape of the bank which gives more masonry to soil contact and reduces the potential for leakage and washouts.

E. Settling of Loose Soil in the Banks

While the banks generally were compacted as they were being built, this compaction was seldom complete. When the water was turned into the watercourse, the banks were thoroughly wetted; and when there was traffic on these banks, they generally settled from 0.1 to 0.3 foot below the original design level and the freshly constructed level. To compensate for this settling, it is recommended that these banks should generally be built 0.2 foot higher than the design level and in stretches where there is over 1.0 foot of fill, 0.3 foot higher than designed bank elevation.

F. Channel Bed Levels

Checking the bed levels one month after construction it was found that they were generally 0.1 to 0.2 foot above the design level. This was not generally an accumulation of new sediment but was probably a result of the tendency of the farmers to not believe that we needed to go as deep as we were going in the excavation of this watercourse and the general tendency of humans to do slightly less than is requested! This deficiency in depth was easily corrected during watercourse cleaning by telling the farmers the problem and requesting that they "clean" the watercourse to a depth of about 0.2 foot below the existing bottom level. It would have been very helpful if there had been some profiles of just one layer of bricks coming down the side slope and across the bottom of the bed at the elevation designed for that particular section. Having these profiles at 100-foot intervals would help the farmers maintain the proper cross sections.

G. Farmer Sub-Branches

Following improvement, the farmers receive almost twice as much water as they have been used to in the past at many of the junctions toward the bottom end of the watercourse. The absolute increase in amount of water flowing and the increased head gradient necessary to force this larger volume of water through a given channel act together to raise the height of the water at the top end of the sub-branches and in the immediately adjacent sections of the branch watercourse which delivers the water to these sub-branches. Overtopping occurred at several such junctions and in their vicinity. On seeing this overtopping CSU and the resident agricultural engineers built up these junctions and the adjacent banks, rather than telling the farmers to increase the side of their sub-branches to handle their new increased water supply. Noting that we had done this at a few junctions many of the other farmers took this easy out and requested that their junctions be similarly built up. By going along with these requests we missed the ideal opportunity of demonstrating to the farmers: (1) the correctness of the watercourse design, and (2) the fact that their watercourse sub-branches needed to be improved to handle this flow. It also negated one of our original design features which was to have the top of these structures at a level just 3 inches above the design level so that these structures would serve as an over-flow in case of spurious high flows of water down these water-courses, inadequate cleaning of the watercourses, or accidental closure of the nakkas. They were to act as a safety valve allowing the water to flow on down the channel rather than to erode over the banks and destroy the earthen banks. In future projects the farmers should be told before they begin that this is going to happen and that they should look for it as an evidence of their increased water supply rather than a deficiency in the design. Before it happens we should encourage them to either enlarge their sub-branches or to split their water into two or more of these sub-branches.

H. Poor Performance and Participation of Farmers in the Final "Touch-Up"

By the time the farmers finished the main excavation work they were understandably eager to return to their farming activities. The extension supervisor was able to coax them into a couple of days of a very haphazard effort by a large crew who walked along the watercourse filling the observable holes with soil. The soil was placed in these holes so loosely that within a few weeks a large portion of these holes were leaking again. The job was originally planned to be done by two small crews of men (about 4 or 5 men each) who were to be carefully instructed and supervised. The first crew was to have gone through the watercourse and carefully compacted the earth into all observable holes and then the second team was to follow the waribundi schedule and close all remaining observable leaks while water was in the channel section during a complete waribundi turn. The rates of loss from this watercourse could probably have been reduced by at least another 10% had this been done.

In the future the agreement with the farmers should be spelled out including the requirement for this final touch-up effort. On test sections this final touch-up effort was proven to have the highest benefits/cost ratio of any of the farmers' efforts. Having the farmers agree to this component of the improvement program before the work is started will help them pace themselves and prepare for this "supreme effort."

I. Location of Check Structures, Culverts and Turnouts

While there was the equivalent of a couple of days of engineering and extension agent time spent with farmers in determining where the check structures, turnouts and culverts should be, there were many requests and demands for additional check structures, culverts and turnouts following the completion of the watercourse. In the case of check structures and culverts these demands were particularly a problem since the head losses of these additional structures would raise the elevation of the water surface above that in the original design. Unfortunately, the original criteria for placement of these check structures and culverts was violated for what appeared to be a couple of hardship cases. Within about two days every farmer on the watercourse had heard of these exceptions and many of these were asking for additional check structures and nakkas. In future pilot-improvement programs the criteria for placement of these structures should be spelled out to the farmers in the original agreement. More time should be allocated to discuss the locations of these structures and the reasons for the criteria with the executive committee and the individual farmers. Then, once the watercourse has been designed, there should be absolutely no deviations from these designs. This will allow the engineers, when approached by the farmers for additional structures, to lay the responsibility for this decision with the supervisors of the project, rather than have to personally turn down the request of the farmer whose cooperation is essential to the success of the project.

FINDINGS APPLICABLE TO FUTURE PROGRAM DESIGN

Even though this was an experimental watercourse on which there were many expenditures for experimental structures and many persons were assigned to the watercourse primarily for training, the benefit/cost ratio still appears to be in the range of 3-4.

This indicates that in more refined development projects to be scheduled in the future that this benefit/cost ratio could be increased to 5 or 6. However, the longevity of these improvements will be highly dependent on a well-scheduled and quality-controlled maintenance and cleaning program. Even at this early stage it is apparent that the farmers need help in scheduling maintenance because there have been periods when the farmers have allowed the sediment basin to fill and overflow into the regular watercourse channel. Combined with plant growth in the channel, this sediment accumulation has raised the elevation of the water at the head of the watercourse to the point that the mogha was being submerged and the flow of water from the distributary to the farmer's watercourse reduced appreciably below their allocated supply. It is strongly recommended that on this and future improved watercourses special staff gauges fixed at the head of the watercourse be painted red in those elevations where the water in the watercourse will cause reduction of flow from the distributary.

Water losses were found to be a function of the operating level of water in the watercourse, the compaction of the banks, and the thickness of the banks. Losses were generally lower in those portions of the watercourse where the water ran continuously, rather than in those portions of the watercourse where the flow was intermittent (i.e. only one or two days per week). Immediately following the major reconstruction effort there are few rodent holes or insect burrows which extend completely through the banks. However, as the animal and insect population in these banks return to their steady state, it is likely that these banks will again develop higher permeabilities. Regular and consistent closure of leaks should help keep the loss rates down. However, it appears that there is also a good argument for designing the normal flow level in the main watercourse delivery channels to be down near the level of the surrounding fields, using check structures to bring this water level up to the operational level needed at delivery points. The appreciably reduced loss in the continuous flow sections, particularly when those sections are operating at less than full supply level, raises the interesting possibility that dividing the water into two or three continuously flowing channels and revising the waribundi schedule to give the farmers more frequent access to the water may not use an appreciably greater amount of water than is presently being wasted in losses. These possibilities should be further evaluated and analyzed to determine how much they can increase the efficiencies and help the farmers increase their water use efficiency.

Sod placed behind culverts and check structures provided adequate protection from erosion in those channels in which water flowed only one or two days a week. This sod is generally available within a few feet of the watercourse before the reconstruction begins. Some forethought in stockpiling this sod as the banks are torn apart at points where structures will be installed can reduce labor involved in bringing this sod to the points where it is needed. In those sections of the watercourse where water is flowing almost every day, it will be necessary to use some sort of rip rap to prevent the banks from eroding in the vicinity, especially just below the culverts and structures.

Preliminary measurements indicate that the head loss at control structures and culverts can be reduced by 10 to 20% if some form of transition is used to funnel water into these smaller cross-sections. On some watercourses this reduction in head loss will not be significant. However, on sections of many watercourses, saving this much head loss can help get the water to the high points that are difficult to reach. The cost of this funneling is primarily labor, and it generally amounts to only 2 or 3 hours per structure. Putting in a double orifice, though, increases the cost by about Rs. 100 for a check structure and Rs. 200 for a 20-inch culverts.

The submerged orifice-type check structures can be used as measurement structures if the head loss across them is accurately calibrated with the flow through them. This accurate calibration may require stilling wells. Once calibrated, the given size orifice with the standard approach condition and angle of installation with respect to the direction of water flow can be translated to other orifices with identical approach and angle conditions.

The sediment trap works effectively, but the farmers should be instructed more completely on how to determine when it needs to be cleaned and to arrange for its cleaning as soon as it is needed.

The elimination of the parallel sub-branches appears to have been completely successful in the eyes of the farmers who were served by these sub-branches, and this should be a standard recommendation in the future.

One of the biggest sources of contention between farmers and the technical personnel was the desire by every farmer to have a check structure immediately following his take-off from the watercourse. As discussed earlier, this is not only an extra expense, but also is often impossible because of the extra head loss caused by the large number of check structures. In a few cases where there seem to be extenuating circumstances the original design requirements of spacing these check structures at least 500 feet apart were relaxed and the farmers were given extra check structures. Within a few days almost every farmer on the watercourse knew about these exceptions and the project engineers were faced with a flood of requests for additional check structures by the other farmers. Refusal to accommodate all these requests resulted in some hard feelings. Obviously, some rules and regulations regarding these requests need to be established at the outset. Also, the farmers on the watercourse and the irrigation department which readjusts the waribundi must agree to readjustments which will give extra time to those farmers who have to fill up extra sections of the watercourse.

RECOMMENDATIONS AND FUTURE PLANS

A. Watercourse Improvement Program

On the basis of the apparent success of this program it was recommended that a watercourse improvement program of this type be included as a major program in the On-Farm Water Management Pilot Project to be initiated in the Sind, the Punjab and the North West Frontier Provinces of Pakistan.

B. Project Should Continue for Training/Laboratory

This first pilot watercourse improvement project answered many questions which will help the next pilot watercourse improvement project go more smoothly and compensate for leadership components which may not be as strong as the leadership component was in this first pilot watercourse improvement project. However, there are many additional improvements that need to be made in the manner in which farmers are contacted and motivated to participate in watercourse improvement projects. For this reason it is proposed that these projects be continued as training grounds for personnel and as laboratories for developing the most effective means of watercourse improvement.

C. Other Watercourses Should be Tested

Several of the physical procedures used in this project to solve problems were less than completely satisfactory solutions. Several new procedures are suggested by these data and experiences which appear likely to solve the problems more efficiently. Moreover, this watercourse had a primarily loam soil and the branch watercourse went through only a few short stretches of sandy soil. Consequently, there was no necessity for concrete lining of the long stretches of the watercourse. There were no slopes steep enough to cause appreciable erosion; consequently, drop structures were not needed. To meet and solve these additional problems, watercourses with permeable soils, steeper slopes, flatter slopes, serving land areas needing additional water, and surface drainage should be included in the series of pilot watercourse improvement projects.

D. Other Construction Seasons Should Be Tried

This watercourse improvement was conducted during the months of December, January and February when the need for water is low and the temperature is ideal for working. These improvement projects should be tried other seasons of the year when there is a higher demand for the water; there is not a scheduled canal closure, and the weather conditions are not as optimum. Other periods of time which have excess labor in these rural areas include the period immediately following wheat threshing to the middle of July, and the monsoon period from mid-July to mid-September. After the middle of September the farmers are generally becoming eager to get their land prepared for their staple wheat crop. The period from mid-December through mid-March appears to be an ideal period for watercourse improvement and is long enough to allow a technical team to work with farmers and complete two successive watercourses during that period of time. This should be attempted.

E. Essential Improvements Program

The enthusiastic acceptance of this pilot watercourse improvement program by farmers of surrounding watercourses indicates that the demand exceeds the supply of technical and losses in the acceptable range through a regular maintenance and cleaning program has been proposed. The program will utilize staff guage type plates fixed to easily visible pakka structures, will measure losses in the water in the watercourses, will ask the farmers if they would like to know how much a good cleaning increases the supply of water to their fields, and will give farmers information on how much such cleaning procedures have increased water delivery to other fields. The activities and time involved in a good cleaning will be expla'..ed to them and they will be asked if they can provide sufficient help from their village to do a good cleaning. If they can and will complete sets of pictures, still and moving will be taken of the watercourse before cleaning, during the cleaning process and following the cleaning, along with the data on delivery efficiency improvement. Permanent measurement structures will be installed in these watercourses along with the staff guages from which the farmers will measure the water and determine when their next cleaning should be scheduled. This program and variants thereof will be conducted on 16 watercourses in the Mona project area.

G. Irrigation Advisory Service

Extensive application efficiency measurements conducted throughout the past year by Afzal and Clyma (in preparation) have shown that the farmers do not use their water effectively in the production of crops. On the basis of these observations, an irrigation advisory service will be developed, tested, and adapted to the needs of the farmers. This service will provide the farmers with an estimate of the flow of water in their watercourse, the amount of water used by the crops since the last irrigation, and the priority need of this crop as compared to other crops which he is growing with the water available in his next turn. The farmer also will be provided with estimates of the water he will have available and of the consumptive use requirements of various crops and the advisor will then help the farmer plan a crop pattern which will most effectively match his crops to his available water supply.

New methods of surface shaping and water application currently are being tested at the Mona Reclamation Experimental Project and are showing appreciable potential for increased crop yields. As these methods are tested adequately, they will be incorporated into the advice furnished to the farmer in this advisory program.

In the process of water scheduling farmers become very aware of how much time is being used to irrigate each acre of crop. This gives the irrigation advisor the opportunity to tell the farmer the relationship between the time necessary to irrigate the field and how level that field is. Also the advisor can suggest to him that his unleveled fields could be irrigated in less time if he were to level them. Technical assistance and equipment will be made available for the farmer to do this job.

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