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ABSTRACTS OF REPORTS AND PUBLICATIONS

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FOREWORD

This publication contains abstracts of some 154 articles or publications to which the Colorado State University Water Management Research Project in Pakistan has contributed in one way or another. Some of the abstracts refer to material that was published in more than one article or report so that the total number of references is about 190.

We hope that this report will be useful to persons interested in locating materials relevant to water management in Pakistan in particular and to the developing countries in general.

We are well aware that many people have contributed a variety of materials and reports over the years. Undoubtedly some of them have been missed by the compilers of this report. If any of you as readers or users of this publication are aware of publications that should have been included please let us know immediately as this is intended to be an interim report and we hope to rectify any errors or omissions in the final version.

Finally I wish to thank the members of the Colorado State University field party for their many hours spent preparing, compiling and revising these abstracts. I also wish to acknowledge the help of campus staff and last but not least the expert services of our typists Mr. Sabir Hussain, Mrs. Mary Rahm and Mr. Abdul Rehman.

John Reuss
Chief of Party
CSU Water Management Research
Project in Pakistan
Box 660, Lahore.

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SUGGESTIONS FOR READERS

The abstracts compiled in this report are grouped in the eleven categories shown in the index. While these categories should help you locate most of the materials pertaining to a particular subject, many reports actually contain materials appropriate to two or more categories. For this reason a cross reference is provided at the end of each category. This cross reference lists the numbers of the reports assigned to other categories that actually contain a significant amount of material pertaining to the category under which they are cross referenced. Therefore we suggest that if you are interested in a particular subject you should check not only the materials in the appropriate category but also the articles cross referenced under that category.

ABBREVIATIONS USED IN CITATIONS

Ann. Prog. Report	Annual Progress Report (1975 and prior years)
Ann. Tech. Report	Annual Technical Report (1976 and 1978)
CSU	Colorado State University
MREP	Mona Reclamation Experimental Project
WAPDA	Water and Power Development Authority
WMRP	Water Management Research Project

A. MEASUREMENT OF WATERCOURSE LOSSES

A-1

Installation and field use of Cutthroat flumes for water measurement. G. V. Skogerboe, R. S. Bennett and W. R. Walker. Water Mgmt. Tech. Report No. 19, CSU, 1972. 131p.

The Cutthroat flume has been developed for operation under both free flow and submerged flow conditions. The flume has a flat bottom and vertical walls. The most obvious advantage of a Cutthroat flume is economy, since fabrication is facilitated by the flat bottom and removal of the throat section. Another advantage is that any particular flume length has the same convergence, divergence and wall length, thereby allowing the same forms or patterns to be used for any throat width. The use of a consistent geometric shape has facilitated the development of generalized free flow and submerged discharge relations using both English and metric units. Any flume length between 1.5 feet (0.45 meter) and 9 feet (2.7 meters) can be used, while throat widths between 1 inch (2.5 centimeters) and 6 feet (1.83 meters) have been investigated. The differences between free flow and submerged flow conditions are described, together with the necessary criteria for determining which flow regime exists. The transition submergences are listed for the range of flume sizes investigated. For free flow, the ratio of inlet flow depth to flume length should preferably be less than 0.4, while for submerged flow, the accuracy of discharge measurement rapidly deteriorates above submergences of 95 percent. Examples are given which illustrate the design procedure for determining flume size, as well as obtaining the free flow and submerged flow ratings. Proper installation and maintenance procedure for Cutthroat flumes are described.

A-2

Watercourse losses: case study No. 2. Wayne Clyma and Arshad Ali. 1974 Ann. Prog. Report WMRP CSU, p.162-166.

A second case study report has been prepared regarding watercourse losses. A considerable number of seepage measurements have been made for the three study watercourses at Mona Reclamation Experimental Project. The three watercourses are Tubewell (TW) 78 a perennial watercourse, TW 122 a non-perennial watercourse and TW 137 an uncommanded area. Seepage from a watercourse is a function of many factors including rate of flow (discharge) and the wetted perimeter of the channel. Measurements of these parimeters have been made at the three watercourses to arrive at preliminary estimates of seepage rates.

A-3

Watercourse losses. Wayne Clyma, Arshad Ali and Mian Ashraf. CENTO Panel Paper, March 1975. WMRP CSU, 21p.

Watercourse conveyance efficiencies and the corresponding types of losses are described for several districts in the Punjab Province: Multan, Faisalabad, Mona and Sarghoda. Tables and charts are presented to show watercourse losses and the characteristics of watercourses.

Above material found in whole or inpart in:
1975 Ann. Prog. Report WMRP CSU, p.170-191.

A-4

Improved farm water management in Pakistan. Gilbert L. Corey and Wayne Clyma. Water Mgnt. Tech. Report No. 37. CSU, 1975. 32p.

It was found only about 20 percent of water entering the watercourse is available to crops. Average wheat production was increased 2-1/2 times by applying water as needed and using optimum fertilizers. Almost half of the water lost from a watercourse occurs within 30 feet of the junctions. A permanent concrete control structure was developed which often increased the supply of water to the farmers fields by 50 percent for a cost between Rs. 50 and Rs. 90 (10 Rupees = approx. $1 U.S.). Efficiency measurements also

identified that a large portion of the losses were due to the high permeability of the earthen watercourses. A program of compacting the soil banks of the watercourse was found to reduce seepage by 25 percent. A third type of water loss could be eliminated by careful alignment of the bottoms of the watercourse. Because of the high cost of concrete or masonry ($3 - $7/ft) it was generally not economically feasible to line a watercourse unless the water is carried more than 2 to 3 days per week.

Above material found in whole or inpart in:
1976 Ann. Tech. Report WMRP CSU, p.525-531.

A-5
Compacted cores to reduce leakage through watercourse banks.
W. D. Kemper and Mohammod Akran. 1975 Ann. Prog. Report WMRP CSU, p.243-249.

Rate of water loss was reduced by more than 75% through soil compaction. Labor used was 0.06 man hours per foot of watercourse. Benefits exceed costs by a factor of over 30.

A-6
Watercourse leaks. W. D. Kemper, M. Akram, M. Afzal and M. Iqbal. 1975 Ann. Prog. Report WMRP CSU, p.238-242.

A survey of Tubewell 91, MREP area, showed 120 visible leaks through the banks and an additional 40 leaks at junctions. The watercourse was 8,000 feet long. When the tubewell was not operating, only 20 bank leaks were visible. The 20 leaks accounted for 0.14 cfs water loss out of an inflow of 0.69 cfs. Values were put on the water to show the economics of reducing these visible leaks.

A-7
Comparison of watercourse losses measured by flume and ponding methods. Field day report. W. D. Kemper, M. Akram, M. Afzal, Pervez Iqbal and Wayne Clyma. 1975 Ann. Prog. Report WMRP CSU, p.154-169.

These papers discuss the result of a 2 day session organized by WAPDA, Harza Engineering, CSU and other concerned agencies to answer the questions:

1. Are the losses measured by CSU and MREP representative of other areas in the Indus Basin?
2. Are the methods used for measuring the losses adequately precise or biased in any matter?
3. If these new measurements are accurate, what is the reason for such losses?

This first meeting consisted of a three hour session on July 24, 1975 at which the Director of the Mona Experimental Research Project and CSU personnel described the losses which have been measured, the methods used for measurement and their limitations. Personnel from the other agencies asked questions and described their own experiences with measuring watercourse losses. CSU summarized their water measurement results from over 30 watercourses throughout Punjab Province. Water delivery efficiencies averaged about 60 percent while irrigation application efficiencies averaged from 30 to 40 percent.

The second session was convened on the Mohlenwod Khurd watercourse near Lahore on July 24, 1975. Comparisons were made between the flume and ponding methods for water loss measurements. Both methods, when used carefully, provide good estimates of watercourse loss. However, it was apparent that the loss rate is highly dependent on the level of water in the watercourse. When the water level dropped an inch below the current operational level, losses could be reduced to half their current values. These results emphasize the potential of frequent cleaning of watercourses to reduce water losses.

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A-8

Watercourse losses as related to composition and condition of banks. W. D. Kemper, Wayne Clyma, Moh'd Akram, Moh'd Hanif and Iqbal Parvey. 1975 Ann. Prog. Report WMRP CSU, p.137-153.

Watercourse losses were measured using the ponding method. Bank conditions under study represented those types found in the field most often as well as the compacted banks most desirable. On three soils (loam to loamy sand) 70 to 90 % of the losses occurred in the upper porous part of the banks. Most of the losses encountered could have been stopped by reconstructing the banks with clean compacted soil.

A-9

Pucca nucca losses on Watercourse D of Tubewell 78. Tom Trout and M. Akram. 1975 Ann. Prog. Report WMRP CSU, p.250-252.

Water losses through 11 improved outlets on Watercourse D, Tubewell 78, were measured. The type of nucca, measurement method and loss are listed. Total losses from the 11 nuccas were less than 1% of the total inflow. Permissible water loss for a watercourse should be determined before nucca selection and design. A total nucca loss of 1 to 5 % should be allowable.

A-10

Water losses from Watercourse 62394L (Tubewell MN-56L). S. A. Bowers, Bashir Ahmad, Ch. M. Hayat Khan and M. Azeem. 1976 Ann. Tech. Report WMRP CSU, p.105-116.

An analysis was made of steady-state flow rate values measured at the watercourse head and at various distances down channel both before and after earthen improvements. Based on numerical averages improvement increased the average delivery efficiency from 48 percent to 70 percent; the increase in average flow rate to the farmer field channels was 76% or 1.58 cusecs. Watercourse improvement did not increase the delivery efficiency of the main channel which flowed almost continuously, this was attributed to its almost continuous flow which was thought to help maintain better channel seal. Regression equations were also developed to relate loss rate to distance and to initial flow rates. Recommendations were made that future before and after improvement steady-state flow measurements be made at comparable distance and initial flow rates.

A-11

Water loss measurements on Watercourse 50440L (Tubewell 51). M. Azeem Chemma, M. Akram, M. Yasin and S. A. Bowers. 1976 Ann. Tech. Report WMRP CSU, p.83-90.

The effectiveness of watercourse improvement is based on losses measured before and after improvements. Despite the fact that watercourse 50440L was relatively efficient in water conveyance, renovation decreased losses by about 20%. Loss reduction through renovation varied from 12% to 40% on several branches.

A-12

Improvement and maintenance of earthen watercourses to reduce waterlogging and increase water supplies for crop production. W. D. Kemper, W. Clyma and M. M. Ashraf. Publication No. 50, MREP (WAPDA) and WMRP CUS, 1976. p.17.

Magnitudes and types of watercourse losses in the Bhalwal, MREP area are explained in detail. Cost-benefit ratios show that watercourse improvement is the best method for gaining water for production. Charts and diagrams are presented to exemplify high operating water level problems. Schemes for structures and watercourse design are shown.

A-13

Review of watercourse loss measurements in Pakistan. Mian Ashraf, W. D. Kemper, M. M. Chaudry, E. Ahmad and Tom Trout. Tech. Publication No. 71, MRLP (WAPDA) and WMRP CSU, June 1977. 45p.

Various agencies have reported on watercourse losses in Pakistan (Kennedy, Benton & Blanch; Hunting Technical Services; IIMI; Boom & Gerards; WAPDA/CSU). Tables are prepared that show the agency, where measurement sites were located, the loss measurement method used, and the resultant losses. The ponding method and inflow-outflow method for computing watercourse losses are compared for different test sites. Reasons for loss differences because of method are discussed in detail. The difference between average operational losses as measured by WAPDA-CSU and LIP-IRI is about 40% (50 % versus 10 %).

A-14

Operational conveyance losses on two Punjab watercourse systems. Tom Trout. Procedings ESCO Seminar on Water Mgmt. Lahore, Pakistan November 1977. WMRP CSU, 20p.

Volumetric water inflows and outflows were determined on one SCARP and one non-SCARP watercourse conveyance system in the Punjab. The study involved constant measurement of canal outlet and public tubewell inflows, and of all water passing through outlets into farmers' fields during a one week rotation period. This type of study enabled a determination of not only steady state loss rates, but of operational losses including dead storage, infiltration into dry banks, and losses during channel filling and drainage. The total conveyance losses on the two watercourses was 37 and 56 %. About 8% of the inflow was lost to transient (non-steady state) losses, implying that past steady state measurements underestimated true operational condition losses by 8 percentage points. About half of the transient losses were dead storage. The steady state wetted perimeter infiltration rates were much higher than surrounding field intake rates, and were highly variable, indicating that much of the loss can be eliminated without channel lining. Statistical analyses were run between loss rates and measured watercourse design parimeters to try to understand the system better and to enable redesign of earthen watercourses to reduce conveyance losses.

Above material in whole or in part found in:
WMRP Field Report No. 7 CSU 1975. 30p.
1976 Ann. Tech. Report WMRP CSU, p.230-272.

A-15

Watercourse conveyance losses in the Mona Reclamation Experimental Project Area. Tom Trout and Muhammad Munir. 1976 Ann. Tech. Report WMRP CSU, p.193-205.

Upon recognizing that the efficiencies of the watercourse conveyance systems were much less than had been previously predicted, a program to determine the extent of watercourse losses was undertaken at Mona. A summary of the results of measurements on over 250 sections concentrated on 9 watercourse systems is presented. The conclusion is that 30% to 50% of the inflow is lost before it reaches the fields. In response to this finding, a watercourse renovation program was undertaken as a low cost means for reducing water losses. Data presented from the first two watercourses thus improved indicated that the losses can be reduced by 50% through watercourse earthen improvement.

A-16

Water conveyance losses on Tubewell 81-F watercourse after improvement. S. A. Bowers and Mohsin Wahla. 1976 Ann. Tech. Report WMRP CSU, p.273-289.

Based on integrated flow volumes into the watercourse and out to the field, earthen improvement increased the watercourse delivery

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efficiency from 44 percent to 57 percent. Improvement increased delivery to the fields by 4.08 ac. ft. per seven day irrigation turn. This was enough water to irrigate 13.5 additional acres. Seventy-three percent of the loss occurred in the government authorized and located channels; 27 percent was lost in farmer field channels. Significant differences between night and day losses were not detected.

Using steady-state flow data watercourse conveyance losses both "before" and "after' improvement losses were mathematically described through derived regression equations. Solutions to these regression equations predict the watercourse loss rates before and after improvement are almost equal for initial flow rates of 1.75 cusecs.

A-17
Complete operational irrigation evaluation of three watercourse systems. C. Rahmat Ali, et al. Publication No. 1, WAPDA CSU, August 1978. 60p.

An in-depth water loss study was conducted on three seperate watercourses during a 3 - Week period. Steady-state water losses were measured along with transient losses. Inflow rate to the watercourse consistently affected loss rate as the rate of loss increased exponentially with rate of inflow. One third to one half of total water losses occurred in the farmers' branches. Stopping leakage on the sarkari khal sections (public) will save 1/2 to 2/3 of total conveyance losses. About 1/2 of the fields were irrigated within 40% above or below the soil moisture needs. Deep percolation losses varied from a high of 71% of applied water on sandy soil to 16% on medium soil.

Cross References

Additional information related to this subject may be found in the following publications.

B-6, B-8, B-9, B-10, B-15, B-17, B-18, E-13, F-6, H-5, I-7, I-10,

I-14, K-1, K-2, K-18.

B. IMPROVEMENT OF FARM WATERCOURSES

B-1
Planning sediment distribution in surface irrigation. K. Mahmood. Water Mgmt. Tech. Report No. 26. CSU, 1973. 67p.

The object is to route water and sediment through an irrigation canal network so that sediment discharge equilibrium is achieved by diverting the sediment inflow through the farm supplies. A computer-simulated canal network is used for the routing and following conclusions are reached. (1) The sediment transport capacity in a branching canal network reduces in the downstream direction, mainly because smaller channels cannot transport their proportional share of the sediment load in the system. (2) The sediment transport capacity of farm watercourse channels is especially limited and sediment discharge nonequilibrium in these channels can cause frequent interruption to farm water deliveries. (3) Sediment inflow on farm units necessitates recurrent land leveling. General principles for planning the sediment routing are derived. Results of laboratory and computer studies of sediment withdrawal in farm turnouts are also presented. The design of system components so as to achieve sediment discharge equilibrium is illustrated by a numerical example. Subject areas, where existing knowledge is deficient or unavailable, are also identified and specific topics for field research are suggested.

B-2
Preliminary comparison of bullock power and hand labor for moving soil into a watercourse pad. Alan C. Early and W. D. Kemper. 1974 Ann. Prog. Report WMRP CSU, p.174-176.

A comparison was made of building a watercourse pad using hand labor and a bullock drawn 42" wide fresno scraper. 20 men could build 30" of pad in 3 hours or 0.5 ft. per man hour. The fresno scraper built about 5' per hour. The cost of building pads based on these figures is Rs. 3.2/yd^3 by hand and Rs. 1.3/yd^3 by bullock with fresno. Using a 65-hoursepower tractor with 8' scraper the cost is reported at about Rs. 1.0/yd^3. A second advantage of using a scraper is that the adjoining fields can be left in much better condition for agriculture.

B-3
An Approach to the structure of a farm water management loan. Jerry Eckert, Niel Dimick and Wayne Clyma. 1974 Ann. Prog. Report WMRP CSU, p.439-479.

This report presents a first approximation of the structure of a water management program which the GOP could consider implementing with the assistance of a USAID water management loan. Suggested program components are discussed conceptually and their estimated costs and benefits specified. An adequate water management program in Pakistan must have three components: 1) land leveling; 2) watercourse improvement, and 3) irrigation and irrigated cropping extension.

B-4
Nakka and diversion designs. W. D. Kemper, et al. 1974 Ann. Prog. Report WMRP CSU, p.177-181.

Three nakka plans are shown and their installation is discussed. One nakka involves brick masonry with a wooden gate. The other two plans include either fired clay or concrete pipe with circular lids. A type of diversion or division structure is shown involving precast concrete panels and circular concrete lid.

B-5
Check and gate development for Pakistan and other lesser developed countries. William E. Hart. 1975 Ann. Prog. Report WMRP CSU, p.253-257.

Five types of nakkas are used in discussing installation, use and cost. Pipe nakka costs (12-inch) varied from Rs. 91 to Rs. 99. Rectangular concrete nakka costs were Rs. 61 and 12-inch sock nakka cost Rs. 66. The sock nakka was least satisfactory in the field.

B-6
Manual construction of an experimental watercourse at Phullerwan Farm. Tom Trout and Ch. Karim. 1975 Ann. Prog. Report WMRP CSU, p.235-237.

A 4000-foot watercourse was constructed to deliver accurate flow rates under varying conditions to experimental plots. The watercourse section was split into 200 foot sections, water loss rates measured and results analyzed. Cost of construction details are included.

B-7
Monitoring sediment removal and accumulation in the new watercourse served by Tubewell 122. Moh'd Akram, et al. 1974 Ann. Tech. Report WMRP CSU, p.167-173.

The purpose of the study was to relate sediment accumulation in the watercourse to flow rate and hydraulic gradient. With few exceptions, the sediment generally accumulated when the hydraulic gradient was less than 0.4 ft/1000 feet and sediment was removed when that gradient was exceeded. Sediment size consisted mainly of silt and sand. Clay particles moved through the system.

B-8
Watercourse improvement: Methods costs, and loss rates at Tubewell 78 watercourse. Mohammad Akram and W. D. Kemper. 1976 Ann. Tech. Report WMRP CSU, p.91-104.

The ponding method was used to measure watercourse losses. Losses were then appraised numerically with regard to condition of watercourse, whether it was unimproved or earthen improved or brick masonry. A coat of plaster is recommended to seal watercourse sections built with brick and concrete. Water losses of earthen watercourses in sandy loam soils can be reduced 20 to 35 % by thorough compaction of the watercourse bed and banks.

B-9
Pakka structures for improved watercourses their design, construction and use. M. Akram, et al. 1976 Ann. Tech. Report WMRP CSU, p.151-197.

Nearly half of the total watercourse losses occur in the vicinity of junctions where borrowing of soil takes place. Guidelines are presented for the proper selection of materials, design and construction techniques for pakka structures. Design drawings, materials details and cost data are included for nakkas, culverts, buffalo baths and wash stations. Most of the structures have not been tested for durability.

B-10
Design data and equipment development for watercourses. William E. Hart. 1976 Ann. Tech. Report WMRP CSU, p.198-220.

A preliminary for a structural handbook for watercourses is presented. Rating curves, using Manning's equation, are given for for rectangular and trapezoidal channels. Detail drawings are made up for the forming of concrete gates. Model studies were used to determine headloss characteristics of fully open gates.

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B-11
Soil cement blocks for watercourse construction and sediment utilization. W. D. Kemper and Mohd Akram. Research Report MREP (WAPDA) p.1-18.

Sediment for soil cement blocks was taken from watercourse accumulations. Normally, the blocks are manufactured from field soil. After curing and drying, the sediment blocks had considerably more strength than field soil blocks. Composition of the watercourse sediment and field soils is given. This type of sediment cement block could be used for watercourse lining.

Above material found in whole or in part in:
1976 Ann. Tech. Report WMRP CSU, p.75-82.

B-12
Aids for watercourse design and improvement. W. D. Kemper, et al. 1976 Ann. Tech. Report WMRP CSU, p.117-150.

Graphs are developed to assist the beginning watercourse designer in selecting the proper watercourse dimensions, based on Mannings equation. Side slope designs of vertical, 1:2, 1:1 and 2:1 are used in the graphs with variations of "N", slope, velocity and flow depths. All units are in metric. Helpful hints to analyzing watercourse problems and sample solutions to problems are presented.

B-13
Motivating and organizing farmers to improve their watercourse. Mohommad mohsin Wahla, Sidney A. Bowers and W. D. Kemper. 1976 Ann. Tech. Report WMRP CSU, p.440-454.

This paper describes the process of watercourse improvement on the first watercourse improved by the Mona project in their pilot project at Tubewell 56 (village 10 ML). Data are presented on the warabundi, land holdings, watercourse layout and cropping patterns. This is accompanied by a discussion of methods used to motivate the farmers, duties assigned to the executive committee, and establishing a khal chowkidar. Reasons for the success of the project are given.

B-14
Watercourse improvement: Tubewell 56 R during Ramazan. Mohsin Wahla, Malik Mohd. Eqbal, W. D. Kemper and S. A. Bowers. 1976 Ann. Tech. Report WMRP CSU, p.440-454.

Reasons for selection of the watercourse at Tubewell 56R for improvement and the process of improvement are discussed. The farmers agreeed to pay the cost of the control structures in return for the Mona project paying for pakka lining of the watercourse through the village. The farmers were able to buy the structures for 25 percent less than the government pays. Mona personnel avoided involvement in disputes by emphasizing the executive committee's authority in these matters.

B-15
Watercourse improvement in Pakistan: pilot study in cooperation with farmers at Tubewell 56L. CSU Field Party and Mona Reclamation Project Staff. Water Mgmt. Tech. Report No. 45. 93p.

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 (Rs. 10 = $1.00 US) 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 investmant 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.

Above information in whole or part found in:
1976 Ann. Tech. Report WMRP CSU, p.400-439.

B-16
Feasibility and design of a low - head jet pump for irrigation in Pakistan. Rick Aust. 1978 Ann. Tech. Report WMRP CSU, p.355-369.

It is fairly common for tubewells to discharge into watercourses in which either the water level is too low or the discharge from the tubewell raises the watercourse to where the mogha (canal outlet) becomes submerged. A horizonal jet pump was tested in a simulated watercourse to determine whether the hydraulic energy in the discharge of a tubewell could be used to raise the down stream water level in the watercourse it is serving.

Efficiency was studied relative to flow ratios, location of the driving nozzle, length of the mixing chamber and head capacity curve. The maximum efficiency achieved was 42%. This changed only 4% with flow rate change of 30%. The head capacity curve appears linear. Mixing chamber length is critical with the most efficient length being 56" plus diffuser. The cost of a jet pump at an existing tubewell along a watercourse is estimated at $ 158 based on 1978 labor and material prices.

B-17
Simplified design of earthen watercourse improvements. A. C. Early, W. K. Twitty and Hayatullah Khan. 1978 Ann. Tech. Report WMRP CSU, p. 314-342.

A complete step-by-step procedure is set up for the purpose of designing watercourses for improvement. Manning's equation, $V=\frac{R^{2/3}S^{1/2}}{n}$ is explained and sample problems are worked for the reader. Nomographs are presented with Manning's "n" equal to 0.04 and ranges in slope, discharge, and channel configurations. The mathematics of culvert design is discussed and sample problems are shown. Sample worksheets are prepared to assist the designer in data collection and layout for watercourse improvement.

B-18
Low cost farm irrigation control structures for Pakistan. M. Munir, S. Shafique and Tom Trout. International Seminar on Low Cost Structures, Lahore, Pakistan. February 1978.

A consistent problem area on Pakistan inefficient watercourse conveyance systems are the junction areas. Earthen outlets and

checks are built and destroyed each week by the farmers when switching water from one branch to another. The earthen bunds often leak and the adjoining watercourse is enlarged and weakened from the weekly borrowing of water. Recognizing this problem, the development of permanent low cost irrigation control structures was undertaken. A summary of the development is given along with descriptions and drawings of recommended designs. The most successful outlet described is a precast reinforced concrete panel with a circular orifice and lid which is installed in a brick masonry installation and which costs under Rs. 200.

B-19
Determining minimum cost crossections for lined channels. Tom Trout. Symposium on Low Cost Structures. CSU PAK Report No. 35. 1978. 21p.

Reducing channel lining costs involves not only utilization of low cost materials, but also optionally using these materials to convey the required flow. A mathematical treatment is presented for determining the minimum cost cross section shape and dimensions which will fulfill the hydraulic requirements, according to Manning's equation, for various bed side wall material costs. A practical example of line watercourse design is given to explain the utilization of the results. Nomographs are presented to simplify the minimum cost design process.

Cross References

Additional information related to this subject may be found in the following publications.

A-5, A-6, A-9, A-10, A-11, A-12, A-14, A-15, A-16, A-17, B-14, E-1, E-3, E-4, E-6, E-8, E-9, E-11, E-12, E-13, G-10, H-5, I-3, I-5, I-7, I-10, I-11, I-14, K-1, K-9, K-10, K-11, K-12, K-13, K-15, K-17.

C. WATER APPLICATION AND CROP WATER USE

C-1
Evaporation and irrigation water requirements for Pakistan.
Wayne Clyma. Bulletin of IDFCR Council (Pakistan) Vol. 3, No.2, December 1973.

Mean annual potential evapotranspiration for Sargodha using the Jensen-Jaise method is estimated to be near 6 feet per year. With wheat during rabi and cotton during kharif, evapotranspiration ranges from 3.6 feet in a wet year to 4.0 feet in a dry year. Net evapotranspiration requirements range from 2.0 feet in a wet year to 3.5 feet in a dry year. Total seasonal water required to grow two crops ranges from 40 to 60 percent of potential evapotranspiration. Water supplies in Pakistan are short when compared to potential evapotranspiration. When compared to net evapotranspiration requirements for the average cropping intensities, improved on-farm water management can result in considerable savings of water.

C-2
Irrigation practices and application efficiencies in Pakistan.
Wayne Clyma, Arshad Ali and Mein Mohammad. 1974 Ann. Prog. Report WMRP CSU, p.218-243.

Pakistan farmer irrigation practices were studied in detail for about one year. Effectiveness of irrigation water use was quantitatively evaluated in terms of irrigation application efficiency. Charts were prepared showing the various irrigation application efficiencies of a variety of crops throughout the year. Irrigation efficiencies varied from 15 to 100 % with a median near 25%. Median irrigation applications were measured as exceeding 5 inches.

C-3
Consumptive use of irrigation water by major crops in Pakistan
C. J. deMooy, H. M. Bhatti, M. A. Chemma, M. Khalid and W. R. Schmedl. 1974 Ann. Prog. Report WMRP CSU, p.115-126.

Periodic gravimetric determinations of soil moisture profile to a depth of 60 inches and precise measurement of applied water indicate total water used by wheat, berseem, cotton and wheat crops were 22.6, 29.0, 33.9 and 18.5 inches respectively. The fact that the "use" calculated from profile water depletion exceeded the calculated potential evaporation indicates some depletion by drainage from the root zone. The depletions in the lower 2nd, 3rd, 4th and 5th feet of the profile during early season growth also indicate appreciable depletion by drainage. Reliable estimates of water needs of field crops produced under conditions of reasonably high application efficiencies are needed for sound planning of irrigation water use. These studies at PARI are providing this information.

C-4
Consumptive use of water by wheat under optimum management conditions.
Ghulam Haider, M. A. R. Farooqi and C. J. deMooy. 1974 Ann. Prog. Report WMRP CSU, p.90-114.

Water use by wheat came to 18.1, 18.4 and 13.9 inches of water when irrigated at 2, 3 and 4 bars tension respectively. Irrigating at 4 bars of tension (13.9 inches of water applied) did not appreciably reduce wheat yields compared with the other treatments. This study indicates that delaying irrigation until there is a real need for water can save considerable water as compared to the previously recommended applications of up to 24" of water.

During the active growing period of wheat the experimentally obtained values of evapotranspiration agreed very well with the potential evapotranspiration rate, calculated by Jensen and Haise formula under M_1 and M_2 treatments. At early and late stages of growth, however, the expefimentally obtained values were lower than the calculated ones as would be expected. In the 4 bar treatment the actual evapotranspiration rates were less than the calculated rates during the entire season. Wheat crop when irrigated at 14.5% of the available moisture left in the soil or at 46.2% of the field capacity gave the best results.

C-5

Plant uptake of water from a water table. Chaudhry Nuruddin Ahmad. Water Mgmt. Tech. Report No. 41. CSU 1975. 88p.

Groundwater quality in different parts of Pakistan is highly variable. However, there is a thin fresh water aquifer overlying much of this saline water zone. Deep pumping is not possible in this area. A suggestion has been made that the fresh water be recovered by installation of low capacity skimming tubewells. Another suggestion is the direct utilization of groundwater by plants by installing open or closed subsurface drainage system and stabilizing the water table at a specific depth. Under the latter situation the plants would meet a small part of their requirements for surface irrigation but a major part could come from the grounwater reservoir. A review of studies was made to gain knowledge concerning the zone of water uptake so as to estimate the contribution of the groundwater available to plants.

Research carried out in this connection revealed that under a constant boundary condition in which the water table is maintained at a fixed shallow depth it was possible to predict the zone of water uptake. Soil water evaporation data indicated that nearly 90 percent evaporation took place within the upper 150 cm. This loss could be avoided by gowing suitable crops and keeping the water table at a constant shallow depth.

Above material in whole or in part found in:
1974 Ann. Prog. Report WMRP CSU, p.186-188.

C-6

Irrigation practices and application efficiencies in Pakistan. Wayne Clyma, Arshad Ali and M. M. Ashraf. Water Mgmt. Tech. Report No. 39. CSU, 1975. 36p.

Farm water management practices have been studied in the MREP area of SCARP II for approximately one year. Over-irrigation is a frequent occurrence caused by improper methods for determining how much water was applied, inadequately leveled and improperly designed fields. Excessive applications are more frequently made early and late during the cropping season and not enough water is applied during periods of peak water use resulting in water stress and reduction in yields.

Irrigation application efficiencies measured on farm fields ranged from zero to 100 percent. The median application efficiency was near 20 percent compared to the 85 percent assumed in the planning of the SCARP programs. The results suggest a need for improvement of farm water management practices in Pakistan.

The above material in whole or in part found in:
Irrigation practices and application efficiencies in Pakistan: Wayne Clyma, Arshad Ali and Mohammad Ashraf. Publication No. 36, WAPDA. Joint contribution from CSU and MREP, CMO, Master Planning Division January 1975.

C-7

Calibration and application of the Jensen-Haize evapotranspiration equation. Wayne Clyma and M. R. Chaudhry. Water Mgmt Tech. Report No. 40. CSU, 1975. 16p.

This paper presents the procedure for calibration and application of the Jensen-Haize evapotranspiration equation to estimate the consumptive use of various crops using maximum and minimum air temperatures and solar radiation. By the use of this equation and Jensens crop coefficients the potential evapotranspiration and actual evapotranspiration were calculated for wheat during the 1967-68 season at Sargodha, Pakistan.

Above material in whole or in part found in:
1974 Ann. Prog. Report WMRP CSU, p.127-142.

17

C-8

Consumptive use of water under optimum management conditions for major crops in Pakistan. S. A. Bowers and Shahid Ahmad. 1976 Ann. Tech. Report WMRP CSU, p.300-307.

This project was organized with PL-480 funding for the purpose of determining the consumptive use of water by the major Pakistani crops under optimum management conditions. A secondary objective was to train Pakistani scientists in consumptive use measurements and optimum management techniques.

The project consists of seven experimental sites located throughout Pakistan. It is administered through Pakistan's Agricultural Research Council with Colorado State University assisting as a technical advisor. Crops selected for each site depend on local conditions and crops adaptability; however, procedures at all sites remained very similar.

Experiments at each site utilize three moisture stress treatments and two fertilizer treatments. Actual seasonal consumptive use is determined by a strict accounting of all soil moisture additions and depletions, soil moisture contents were determined gravimetrically. Potential evapotranspiration is estimated using the Hensen-Haise equation.

The results will be published in Pakistan and utilized in irrigation scheduling and other water management research. The lack of expertise and organizational problems have been the major constraints in the project. Some sites have not received the necessary measuring and recording instruments yet. Inspections in 1976 show continuous improvement in the quality of work at most sites.

C-9

Consumptive use of irrigation water by major crops in Pakistan. C. J. deMooy, H. M. Bhatti, M. A. Cheema, M. Khalid and W. T. Franklin. 1976 Ann. Tech. Report WMRP CSU, p.288-299.

Periodic gravimetric determinations of soil moisture profiles to a depth of 60 inches indicated consumptive use of water by wheat, berseem, cotton and wheat crops of 22.6, 29.10, 33.9 and 18.5 inches, respectively. Daily rates of actual and potential evapotranspiration are discussed.

Reliable measurements of the consumptive use of water of field crops produced under good management conditions are much needed for sound planning of irrigation water use. Experimental fields at PARI, Lyallpur, have provided such information for wheat, berseem and cotton.

C-10

Estimation of consumptive use of water for wheat under optimum management conditions. G. Haider, M.A.R. Farooqi and C. J. deMooy. 1976 Ann. Tech. Report WMRP CSU, p.308-335.

This study was carried out to estimate the consumptive use water requirement of wheat under optimum conditions of management, mineral nutrition and water supply on demand indicated by soil moisture tension. The consumptive use came to 18.10, 18.37 and 13.92 inches of water when irrigated at 1, 2 and 4 bars moisture tension, respectively. There was no significant difference in yield among these treatments. During the active growth period of wheat the experimentally obtained values of ET agreed reasonably well with the ETo rate calculated by Jensen-Haise equation at 1 and 2 bars tension. Crop coefficients averaged 0.74 for 1 and 2 bars stress plots and 0.59 for the 4 bar stress plots.

C-11

Irrigation advisory assistance. J. O. Reues, M. Saeed, M. Afzal, Hyat Ullah and Wayne Clyma. 1976 Ann. Tech. Report WMRP CSU, p.455-470.

A pilot program for farmer irrigation advisory service is being conducted at the Mona Reclamation Experimental Project. The objectives of this program include, (1) to devise methods of projecting farm water requirements and identifying periods of potential deficiency

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or excess and (2) to test these projections and provide recommendations for cropping changes based on these projections in actual farm situations. The procedures used and data base upon which these projections are based are given.

C-12
Irrigation scheduling in Pakistan. Mustaq A. Gill, M. S. Thesis Department of Agricultural Engineering, Colorado State University, Fort Collins, Colorado. Fall 1977.

To determine the proper amount and timing of irrigation, different methods of determing crops peak water use were compared. Water use as estimated from pan evaporation was more closely correlated to actual water use under the conditions of the study than were estimates using the empirical equations. Consequently, estimates of water use based on pan evaporation are recommended for use in this area.

The need for an irrigation extension advisory service to provide scientific irrigation scheduling services to Pakistani farmers has been recognized. Accordingly, scientific irrigation schedules were prepared for a maize crop. Recommendations were made regarding reorganizing the existing institutional infrastructure both in public and private sectors to implement on-farm water management in Pakistan with irrigation scheduling as its basic component.

C-13
Consumptive use requirements for crops and critical stages for irrigation. J. O. Reuss. Esso Water Management Seminar. Lahore, Pakistan November 15-17, 1977. 19p.

This paper was the keynote address for the consumptive use session of the above seminar.

The author provided a brief technical resume of the application of various methods of estimating potential evapotranspiration and crop consumptive use under local conditions. While any of several of these methods may be successfully used the simple pan evaporation method may be particularly well suited here due to generally low wind velocities. The author also stressed the need for emphasizing water use measurements on reference crops. Most local research is largely concerned with estimating coefficients for consumptive use of individual crops without adequate attention to determination of the accuracy of various methods of estimating potential evapotranspiration through the use of reference crops. The use and limitations of critical crop stage information was discussed. A major point of emphasis is that control of irrigation timing in Pakistan is particularly constrained by the constant flow irrigation system.

C-14
Influence of water level and soil puddling on yield of Basmati rice. S. A. Bowers, Siddique Shafique and M. Yasin. 1978 Ann. Tech. Report WMRP CSU, p.111-119.

A replicated factorial field plot study was initiated to test the effects of puddling, non-puddling and three moisture stress levels on yield of Basmati Rice. Increasing the moisture stress decreased yields from a high of 3.01 Mt/ha for the continuous flooded treatment to a low of 2.27 Mt/ha for the most stressed treatment where water was maintained at field capacity. Although the field capacity treatment yielded the lowest its efficiency (yield/unit water) was the greatest. Reduction of the total water by 40 percent reduced yields 25 percent. When water is in short supply acceptable rice yields can be achieved by holding the soil moisture contents between saturation and field capacity.

C-15
Traditional and improved irrigation practices in Pakistan. Wayne Clyma and Arshad Ali. 1978 Ann. Tech. Report MWRP CSU, p.150-165.

Irrigation practices in Pakistan were observed over a 4 year period. Over irrigation is a common occurrence because of unleveled fields, lack

of farmer knowledge and rigid warabundi turns (irrigation frequencies). Measurements of irrigation application efficiencies indicate a range of 25 to 40 % where public tubewells are the source of water. Application efficiencies under canal command areas are estimated at 40 to 100 % with an average of 60 %. A long list of references follows this state-of-the-art report.

C-16
A computer program for Punjab evapotranspiration estimates. A. C. Early. 1978 Ann. Tech. Report WMRP CSU, p.129-149.

This report provides detailed methodology for the calculation of potential evapotranspiration based on the Penman method using a digital computer program, which is found to be an appropriate method for estimation based on the data base available in Pakistan's Punjab province. Several innovations for facilitating the estimation of the potential day length, the radiation at the outer surface of the Earth's atmosphere and slopes for curves in the psychrometric chart have been included.

A listing of a FORTRAN Computer Program designed to make these calculations is included.

C-17
Irrigation evaluation procedure for flooded rice crops. A. C. Early and Zahid Sayeed Khan. 1976 Ann. Tech. Report WMRP CSU, p.122-128.

Methods are used to take into account the unique consideration for determining water requirements of lowland rice. Procedure is designed to evaluate water use efficiency and to specify the equipment required to collect the necessary data. A data record sheet is prepared.

C-18
Low cost siphons from used tires. Norman Illsley. 1976 Ann. Tech. Report WMRP CSU, p.343-354.

Siphons have been suggested as an improved means of applying irrigation water to fields in Pakistan. Conventional metal or plastic siphons used in western countries are prohibitively expensive to either import or copy locally. Several alternative materials have been considered for making siphons locally. This paper describes the fabrication and performance of siphons made out of used truck and car tires. Fabrication is simple requiring nothing more than is found in the average tire repair shop. Cost of materials and estimated labor should total less than Rs. 10/-($1) each. Flow tests indicate a 7-inch tire can deliver 0.5 cusecs of water at a head loss of 0.15 ft. To prime the siphon both ends are submerged and air is sucked out through a vent hose in the top of the siphon. For good flow and easy priming both ends of the siphon should be submerged. The short radius of a tire requires a narrow ditch bank. Special masonry cores along ditches where siphons are to be used would facilitate their use.

Cross References

Additional information related to this subject may be found in the following publications.

A-4, A-17, B-13, D-4, D-9, D-10, D-11, D-13, D-14, D-15, D-16, D-17, D-18, D-19, E-5, E-13, F-5, H-3, H-5, I-1, I-5, I-6, I-14, K-4, K-5, K-6, K-7, K-14, K-19.

D. SOIL AND CROP MANAGEMENT

D-1

Physical, salinity and fertility analyses of selected Pakistan soils. W. T. Franklin and W. R. Schmehl. Water Mgmt. Tech. Report No. 28. CSU, 1973 29p.

Textural, moisture retention and salinity-related analyses are reported for 58 soil samples representing profiles from 11 sites in the Punjab. These alluvial soils contain more than 45% silt in surface layers at 9 sites and as much as 80% silt in subsoil layers. Thus, the high-silt soils are expected to be subject to weak aggregate stability, compaction and low permeabilities. Soil moisture retention values can be estimated from textural analyses and improved exchangeable sodium percentage estimates from sodium absorption-ratio measurements of saturation extracts can be obtained with regression equations.

The fertility status of 110 soil samples from 4 Pakistani Provinces was assessed. The low organic matter content (<1%) in the alluvial soils explains the large N response found for non-leguminous crops. Available P is deficient (<10 ppm) in most soil surface layers. Available K is generally adequate (>100 ppm) to very high. Available Zn may be inadequate (<1 ppm) for Zn-sensitive crops at about one-third of the sites tested. Iron, Mn and Cu were generally adequate for the large majority of the samples.

Above material in whole or in part found in:
Physical and Chemical Analyses of Punjab Soils. W. Franklin and W. Schmehl. 1972 Ann. Prog. Report WMRP CSU, Appendix 'B' p.56.

D-2

Fertilizer or salt leaching as affected by surface shaping and placement of fertilizer and irrigation water. W. D. Kemper, J. Olsen and A. Hodgdon. 1973 Ann. Prog. Report WMRP CSU, p.1-15.

Irrigation in furrows and placement of fertilizer in bands in the ridges was evaluated as a means for allowing over irrigation to bypass nitrate (NO_3) and reduce leaching losses. In a loamy sand, placement of a band 0 - 5 cm higher than the surface of water in the furrow allowed over 120 cm of over irrigation before the salt began to leave the root zone. In the clay loam a similar delay of NO_3 removal was not achieved until the band was 10 cm higher than the water surface. This difference appeared to be associated with a perched water table that developed in the "cultivated" layer of the clay loam soil due to higher hydraulic conductivity. Over irrigation of 30 cm, applied as basin flooding, leached a major part of broadcast nitrogen fertilizer out of the root zone. Downward movement of relatively concentrated salt solution near the band was a factor that allowed fertilizer bands at lower levels to enter the mainstream of the leaching water.

Leaching of NO_3 from a soil can be delayed by placing it in ridges and irrigating in furrows rather than broadcasting fertilizer followed by flood irrigation. Some of this NO_3 may become trapped in the dry layer at the top of the ridge, but will be made available again if light showers occur.

D-3

Timing and duration of spikelet differentation in semi-dwarf wheat in Pakistan. Jerry B. Eckert. 1974 Ann. Prog. Report WMRP CSU, p.62-64.

Aspecial meristem development in Chenab 70 wheat was microscopically followed at the Punjab Agricultural Research Institute, Lyallpur. Wheat was found to enter the reproductive stage 40 days after planting (d.a.p.) and florets were fully initiated 24 days later with normal sowing dates in early November. When the wheat was sown five weeks later it entered the reproductive stage 54 d.a.p. Once this stage had been reached the differentiation of reproductive parts required the same length of time regardless of planting date. The combination of delayed sowing and delayed reproductive differentiation resulted in the initiation of florets of all spikelets to be 51 days later than normal planted wheat. This causes a compression of the time available

for ear emergence, flowering and grain formation in the spring. Reduced yields are the natrual consequence.

D-4

An action program for water saving and wheat production. Jerry B. Eckert and Armando Campos. 1974 Ann. Prog. Report WMRP CSU, p.270-282.

This report discusses some of the steps that might be taken to avoid a serious reduction in wheat production due to the low surface water supplies and the problems encountered at Tarbela. Three types of actions were recommended which are: 1) increasing planted acreage, 2) increasing yields by the use of other modern inputs and 3) maximizing the efficiencies with which water is used.

D-5

Water management and nitrogen fertilizer movement and utilization in soils. W. D. Kemper, Wayne Clyma, Rehmat and Ghulam Haider. 1975 Ann. Prog. Report WMRP CSU, p.458-465.

This paper discusses the potential for nitrate (NO_3) leaching under various irrigation regions in Pakistan. The theoretical relationship between NO_3 leaching and root expansion are discussed for Rabi and Kharif crops. Suggestions for minimizing leaching are presented. These include split application of fertilizer, elimination of over irrigation, proper timing of fertilizer application, improved irrigation practices, precision land leveling and adequate surface drainage.

D-6

Irrigation method as a determinant of large pore persistence and crust strength in cultivated soils. W. D. Kemper, J. S. Olsen and A. Hodgdon. Soil Sci. Soc. Amer. Proc. 39: p 519-523 1975.

Air-dried soils were wetted by flooding, immersion, slow immersion and capillary action; these actions resulted in successively slower rates of wetting. In general, slower rates of wetting left larger portions of the soil volume in large size pores. Sow capillary wetting of a weakly structured soil allowed retention of more large size pore tha was observed in a well structured soil that was wet rapidly.

Modulus of rupture was determined on dried soils which had previously been wet by rapid immersion, capillary action and capillary action followed by immersion. Breaking strength was much greater when those soils had been wet by rapid immersion than when wet slowly by capillary action. Immersion following capillary wetting resulted in soils with intermediate breaking strengths. A preliminary study on corn seedling mergence showed that the range of soil strengths resulting from these irrigation methods on a weakly structured soil was sufficient to give <50% emergence (flooding) up to essentially 100% (capillary wetting).

Above material in whole or in part found in:
1973 Ann. Prog. Report.WMRP CSU, Appendix C.

D-7

Influence of initial seed moisture content on germination and Emergence of Maize. Larry Nelson and Willard Schmehl. 1975 Ann. Prog. Report WMRP CSU, p.108-119.

Stand establishment has been identified as a major problem in the production of maize and other kharif crops of the Punjab. High daily temperatures, low seedbed moisture and soil crusting are recognized as contributing factors to poor stands. A series of laboratory and greenhouse studies were conducted to determine the effect of initial seed moisture on the germination of cotton, maize and sorghum at varying soil moisture contents.

The results of this study implicate increased initial seed moisture as a factor contributing to better emergence of maize. The practice of sowing maize seed with relatively high moisture contents could

help growers to improve stand establishment, particularly where soil moisture may be a limiting factor. Where high daily temperatures are associated with low seedbed moisture, sowing seed with relatively high moisture contents will probably have to be augmented with extra irrigations.

D-8

Toward optimum management practices for production of maize in irrigated areas of the Punjab. Rehmat Ali, Bashir A. Sabir and C. J. deMooy. 1976 Ann. Tech. Report WMRP CSU, p.345-352.

Traditional practices of maize production are the major cause of the extremely low per-acre yields occurring in many areas. It was found that average maize yields can be doubled by adoption of a package of improved practices. These practices included good seedbed preparation, precision land leveling, the use of good quality seed of High Yielding Varieties, row planting, increased use of fertilizers, improved irrigation practices, and good weed and pest control measures. There were indications that bedding with the accompanying furrow irrigation and the use of farmyard manure could raise the yield of maize to higher levels.

D-9

Effects of delaying the first irrigation on the development of yield components in semi-dwarf wheat. Noor Muhammad Chaudhry, M. Abrahim ad Jerry B. Eckert. 1975 Ann. Prog. Report WMRP CSU, p.434-441.

The effect of delaying the first irrigation of Chemab - 70 wheat from 14 - 43 days after planting on yield components was investigated. A significant reduction in headed tillers for first irrigations more than 21 days after planting was observed. A delay of greater than 49 days reduced the spikelets per head. Similarly, grains per spikelet were significantly reduced after a 49 day delay. The length of delay had no influence on the weight per 1000 grains. Delays of more than 21 days significantly reduced relative grain yield. If delayed until the 35th day, gross incomes could drop to 63.3 percent of its unstressed level.

In practical cropping the most important variable is moisture management between 21-35 days after planting. Due to a linear decline in tillers, yields declined 2.6 percent per day during this two week period.

Above material in whole or in part found in:
1974 Ann. Prog. Report WMRP CSU, p.204-210.

D-10

Effect of flooding and drying on the loss of nitrogen from soil Khalid H. Gill and W. R. Schmehl. 1976 Ann. Tech. Report WMRP CSU, p.60-65.

Greenhouse experiments were conducted to evaluate the effect of cyclic flooding and drying to simulate field conditions on the growth and recovery of nitrogen (N) fertilizer on sorghum. The results of the study indicate that current basin irrigation practices in Pakistan may cause considerable gaseous loss of N from the soil. Although it was not possible to differentiate between the loss of N by denitrification or by ammonia volatilization, it is believed that denitrification was the primary contributing factor. Investigations are needed to evaluate N losses under field conditions and irrigation practices must be developed that minimize these losses.

D-11

Improved soil and water management practices for oil seed production. M. Hanif, F. A. Akhtar, Aleemud Din and C. J. deMooy. 1976 Ann. Tech. Report WMRP CSU, p.353-369.

Field studies were undertaken in an attempt to demonstrate to farmers how the proper use of water, fertilizers, crop production and other optimum crop management practices will result in increased pro-

duction of oil seed crops. Under traditional management practices farmers were unable to make a profit. It was demonstrated that a package of improved practices including balanced fertilizer rates, proper irrigation and adequate plant protection measures raised yields of oil seed crop from 6.68 to 15.68 mds/A, 135%. Using proper fertilization farmers earned Rs. 188/A, when improved irrigation and crop protection measures were added the profits increased to Rs. 235 and Rs. 314/A, respectively. These results demonstrate the importance of improved production practices to the economics of oil seed production in Pakistan.

D-12

Improved soil, water and crop management for increased farm production in Pakistan. Mohammad Hanif and C. J. deMooy. 1976 Ann. Tech. Report WMRP CSU, p.492-524.

Field experiments on wheat, sorghum, maize (fodder) and cotton were conducted to focuse the attention of the potential contribution of irrigation water, fertilization, crop protection and cultural management on yields. The yield of wheat was raised from 24.1 to 53.2 mds/A by application of a package of improved management practices involving fertilizers, irrigation and sewing methods. Maize fodder yields were boosted from 213 mds to 389 mds/A and sorghum from 216 mds to 423 mds/A by means of improvements of which fertilization was the primary factor. Cotton production was increased from 7.3 mds/A under conventional practices to 16.5 mds/A by using improved management practices involving fertilizers, irrigation, line sewing and plant protection. Improved irrigation practices resulted in a saving of 10 inches of water per acre of wheat and 5 inches of water in cotton. Wheat, fodder and cotton farmers can very greatly improve their annual incomes by adopting known improved practices. The net profits increased approximately by Rs. 1100 to Rs. 1200 per acre of wheat and Rs. 700 to Rs. 900 for fedders and cotton.

C-12

Fertility - water interaction experiments on rice at Kala Shah Kaku. A. Majid, M. Saddique and J. Reuss. 1976 Ann. Tech. Report WMPP CSU, p.380-385.

Field experiments were conducted to define the water-nitrogen relationship for high yielding rice varieties in the Punjab. This information is then to be used to develop fertilizer and water management recommendation. Unusually high monsoon rainfall prevented development of moisture stress prior to the final three weeks before maturity. A maximum yield of 72.6 mds/A was attained by irrigation equivalent to 1.6 times (ETp-Rain) ac 150 lbs N. However, a very acceptable yield of 67.8 mds/A was attained with only 50 lbs N and an irrigation treatment of 1.0. Based on these results, plus prevision results, it appears that if water availability is limiting rice acreage it may generally be more advantageous to increase acerage to a point where less than optimum water is applied. Most years the resulting yield decreases apparently will be modest.

D-14

Fertility water interaction experiments on rice at Kala Shah Kaku. Abdul Majid, Jerry Eckert, John Reuss and Sam Johnson. Proc. Rice Prod. Seminar, ESSO Pakistan Fertilizer Co., Ltd. Lahore, Pakistan 1976. p.21-28.

The response surfaces obtained from three years of experimentation on high yielding rice (IR 6-945) at Kala Shah Kaku and least cost alternatives for the use of nitrogen and water are given. Irrigation intervals of ten days or less generally gave maximum yields, but yields in excess of 60 mds/acre were obtained from 15 day intervals in two of the three years. Nitrogen levels for maximum yields varied from 100 to 200 lbs N/acre, but yield increases from application of more than 100 lbs/acre were generally small. Least cost alternative for 60 mds/acre valuing an irrigation at Rs. 30 and N at Rs. 1.5/lb were seven irrigations and 85 lbs N in 1975, 14 irrigations and 172 lbs N. in 1974, and

six irrigations and 25 lbs N in 1973. If water supplies were short, 60 mds/acre may have been an unrealistic goal in 1974 as 50 mds/acre required only eight irrigations and 114 lbs N.

Above material in whole or in part found in
1976 Ann. Tech. Report WMRP CSU, p.386-393.

C-15
Fertilizer water interaction experiment on wheat S. A. Qureshi, Noor Moh'd Chaudry and J. O. Reuss. Field Report No. 5 WMRP CSU, 1976. 37p.

Maximum or near maximum wheat yields can be obtained with three or at most four irrigations after emergence, rather than five to seven previously thought to be optimum.

In an experiment conducted at PARI near Faisalabad during the 1975-76 rabi season the effect of nitrogen, phosphorus and irrigation treatments on root development, yield components and water use by the Sandal variety of wheat was investigated. Early season root and shoot development were both increased by phosphorus fertilizer. Mid season root development between the 1'and 3'depths was depressed by high levels of N and increased irrigation.

Yields of 35 maunds per acre or more were attained by some fertility treatments with only one irrigation after planting, plus 2.34 inches of rainfall. Maximum yield was obtained using 5 irrigations, but the advantage over 3 irrigations was generally small and would probably be nil except for the effect of increased lodging with 3 irrigations caused by adverse weather at the time the final irrigation was applied to the 3 irrigation treatment.

A small increase in use of water by the fertilized treatments was found. However, this does not support the contention that fertilizer should not be applied unless extra water is available, as yield responses were obtained from fertilizer even with only one irrigation.

Another important aspect was that acceptable yields could be obtained with a total use of only 9-10 inches of water used between seedling and harvest, including stored soil moisture, rainfall and irrigation applied well below the amount often considered necessary for wheat production.

Above material in whole or in part found in:
1978 Ann. Tech. Report WMRP CSU, p.70-111

D-16
Evaluation of errors in gravimetric determination of soil water
J. O. Reuss, S. A. Qureshi and Noor mah'd Chaudry. 1976 Ann. Tech. Report WMRP CSU, p.50-60.

Soil water content is measured through sampling and gravimetric analysis. A set of soil moisture data collected from an irrigation-fertility experiment at Punjab Agricultural Research Institute was analyzed. The confidence interval was then determined as a function of number of cores. It was found that 5 cores taken before irrigation would estimate the mean profile water content of 9.5 inches within ± 4 percent of the mean. After irrigation, 5 cores would estimate a mean profile water content of 12 inches to ± 5 percent. However, the difference of 2.5 inches, which represents the use or storage between two sampling dates, is only estimated to a precision of ± 28 percent. This lack of sensitivity must be considered when defining operational or research programs in the field that depend on moisture sampling and gravimetric analysis for evaluating water use by crops.

D-17
Effect of within field elevation difference on cotton stands and yields.
Mohammad Mohsin Wahla and J. O. Reuss. MREP (WAPDA) Publication No. 55. April 1976. 10p.

In this study it was demonstrated that cotton yields in the Mona Project Area are reduced by approximately 50% in the low areas of unleveled fields. While the study does not allow precise evaluation of the fraction of the area on which this reduction occurs, we estimate overall yield reduction at one-sixth of the total yield. This reduc-

tion was caused largely by reduced stands but yields were also reduced where little or no stand reduction occurred. We also estimate that at least 6 acre inches per acre of water that did not contribute to increased crop growth were applied to these fields as a result of their uneven condition.

Above material in whole or in part found in:
1976 Ann. Tech. Report WMRP CSU, p.281-287
1975 Ann. Tech. Report WMRP CSU, p. 94-95.

D-18
Deep water rice variety trial. S. A. Bowers, M. Siddique Shafique and M. Yasin. 1978 Ann. Tech. Report WMRP CSU, p.120-121.

Due to annual flooding, early planting of kharif crops on Ravi River bottom lands is hazardous, all crops including paddy rice can be destroyed. A nonreplicate 70 variety deep water rice trial was planted to determine if early planting was feasible. Twenty-six varieties matured and were harvested in November. All varieties yielded more than the local Basmati; several indicate a high potential for excellent yields under these conditions.

D-19
Water and nutrient response of semi-dwarf wheat under improved management in Pakistan, Agronomic and economic implications. J. B. Eckert, N. M. Chaudhry and Q. A. Qureshi. Agron. J. 70: p.77-80, 1978.

Chenab-70 Cultivar of semi-dwarf wheat (Triticum aestrivum L.) was grown under improved management conditions with several levels of N, P and irrigations. The resulting quadratic production functions indicate that yield levels now obtained by the best farmers can be obtained with one-third to one-half of the water currently being applied if irrigations are timed and controlled appropriately. Fertilizer response also exceeded that obtained by progressive farmers. Economically optimum application rates for water and N were rather restrictive with little opportunity for substitution. Finally, soil moisture measurements coupled with concurrent physiological and morphological observations are used to rationalize the persistence of indigenous cultural practices and to suggest new cultural practices to further enhance irrigation efficiency.

Water and Fertilizer Interactions in wheat production. S. A. Qureshi, Noor Muhammad Chaudhry and Jerry B. Eckert. 1975 Ann. Prog. Report WMRP CSU, p.442-457.

D-20
The fertilizer ratio concept. John Rauss and Sam Johnson, III. The Pakistan Development Review. XVII (I): p. 123-130, 1978.

The concept of optimum plant nutrient ratios has long been utilized by agronomists and is particularly prevalent in Pakistan. In order for the concept to be valid the ratio should be optimum not only at a single rate but at a wide range of doseages. In terms of nitrogen and phosphorus the concept requires that, a generalized N-P response surface exists that is reasonably valid for the fields concerned. Also, the economic optimum will vary depending on the relative price of the input and the very concept of an optimum ratio would place severe constraints on the geometry of the response surface. These limitations of the ratio concept are discussed by the authors in some detail, with the conclusion that the ratio concept at best has very limited validity and is probably much over-used in Pakistan.

Above material in whole or in part found in:
1978 Ann. Tech. Report WMRP CSU, p.370-380.

Cross References

Additional information related to this subject may be found in the following publications.

A-4, A-17, B-13, C-1, C-3, C-4, C-5, C-7, C-9, C-10, C-11, C-12, C-14, C-15, E-3, E-5, E-9, E-13, F-5, F-8, H-1, I-6, I-9, I-10, J-1 J-2, J-3, J-4, J-5, J-6, J-7, J-8, J-9, J-10, K-4, K-5, K-6, K-8.

E. SOCIAL FACTORS AND EXTENSION

E-1

Community and irrigation in the Pakistan Punjab - physical and sociological dimensions of the water management project. David M. Freeman and Max K. Lowdermilk. 1976 Ann.Tech. Report WMRP CSU, p.647-724.

Based on a comprehensive survey of physical and sociological characteristics on 16 watercourses in Punjab, this paper reports data demonstrating low delivery and application efficiencies of irrigation water. Major sociological components of villages, and behavior patterns, effecting water management are discussed. Since improvement in local water management must mean improvement in farmer organizations, three sociological criteria are suggested which, if employed to screen villages as sites for water management programs, are hypotheized to identify the type of social network must conducive to successful farmer organization. These criteria are: 1) degree of conflict polarization; 2) equality of power/influence; and 3) presence of effective leadership on the watercourse.

E-2

Informational sources on water management for agricultural production in Pakistan with special reference to institutional and human factors. G. N. Jones, A. R. Rizwani, M. B. Malik, and R. F. Schmidt. Water Mgmt. Tech. Report No. 31 WMRP CSU, 1974, 170p.

This is a comprehensive bibliography of irrigated agriculture in Pakistan. It deals with a wide range of subject matter though the emphasis is on institutional and human factors. It should be of great help and interest to those seeking informational sources and guidance in analyzing the many complex problems of Pakistan's irrigation system.

E-3

Intensive training program for on-farm water management field extension workers with focus or the Punjab. Alan C. Early, Max K. Lowdermilk and Sam H. Johnson III. 1975 Ann. Prog. Report WMRP CSU, p.475-503.

The purpose of this discussion paper is to examine the need for trained personnel to work intensively with farmers to improve their on-farm water management systems and irrigation practices. The training of the extension field workers who will be required to help implement the on-farm aspects of the USAID-GOP "Water Management Loan" and who will teach farmers how to maximize benefits gained from physical watercourse improvements is of major importance to the success of the program. This extension worker should be trained to help the farmers to more effectively use the services offered by other technical departments such as the Precision Land Leveling Program, the Agricultural Development Bank, or WAPDA. He should remain at the farm level to advise and assist farmers individually and collectively to continue to improve their farming methods and maintain their watercourse system for increased farm production. The findings of a survey of Field Assistants conducted in the Khanewal Extension System are summarized. Survey forms used in collecting the data for the paper are included.

The conclusions of this paper are that intensive on-farm water management improvements are possible on a wide scale in Pakistan only by having trained personnel in the field to help farmers. The intensive training of personnel in methods adaptable to the Pakistan situtations is the first prerequisite for a successful on-farm water management improvement program.

E-4

A study of village organizational factors affecting water management decision making in Pakistan. A. H. Mirza. Water Mgmt. Tech. Report No.34 WMRP CSU, 1975 129p.

The social factors affecting Water Management decision-making of Punjab farmers in a sample of fifteen villages is examined in detail. Three dependent values are focused on: 1) decisions of farmers to

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clean watercourses; 2) decisions to shift from kacha to pakka warabandi systems of water allocation, and 3) decisions to interact with lower level irrigation department employees. The impact of the major dependent variable, presence/absence of public tubewells on the watercourse, is taken to be conditioned by social organizational factors in villages, especially number of agricultural castes, presence or absence of factions and residence pattern. All these factors were found to have a significant impact on decision making and farmers on watercourses augmented by public tubewells were found to mobilize less effort to improve water management than others.

Above material in whole or in part found in:
Water Mgmt. Tech. Report 35.

E-5
Physical and socio-economic dynamics of a watercourse in Pakistan's Punjab: system constraints and farmers' responses. Max K. Lowdermilk, Wayne Clyma and Alan C. Early. Water Mgmt. Tech. Report No.42. CSU, 1975 106p.

A detailed survey of the phy sical and socio-economic conditions of a watercourse in Pakistan is presented. A major constraint on this watercourse was the use of jalars to release canal water for irrigation on much of the commanded area. Major physical problems identified include accumulation of sediment in the watercourse, excessive water-course losses, and both over - and under - irrigation. Farmers seem to have little understanding of the magnitude of their water losses. Experiments with wheat show yields can be doubled even while reducing the amount of water supplied.

Forms of cooperation and organization (mainly around kinship groups), and conflict, are discussed, and the importance of group cooperation for watercourse improvement emphasized.

The results of this study reflect the conditions for only one watercourse in Pakistan. However, the results are so startling in some instances, and consistent with other published data in other instances, that a number of recommendations have been made in this publication.

Above material in whole or in part found in:
1975 Ann. Prog. Report WMRP CSU, p.589-602.

E-6
Organizational alternatives to improve on-farm water management in Pakistan. George E. Radosevich and C. Kirkwood. Water Mgmt. Tech. Report No.36, CSU, 1976. 252p.

A detailed description of the water laws of several selected countries is presented. Setting up local water user associations is advocated as an important step to facilitate improving water management in Pakistan. The procedures and limitations of present laws in Pakistan under associations could be organized is discussed, and a basic design and set of principles, derived from the study of water laws in other countries, is recommended for adoption in Pakistan.

Above material in whole or in part found in:
Water User Organizations for improving irrigated Agriculture: Applicability to Pakistan.
George E. Radosevich. Water Mgmt. Tech. Report No.44
CSU, 1975 34p.

E-7
The need for a water management extension service in Pakistan. Max K. Lowdermilk, Sam H. Johnson III and Alan C. Early. Bulletin of IDFCR Council Vol. 6 (1), June 1976.

This paper reports the results of survey data and engineering field measurements that document the magnitude of losses in Pakistan's watercourses and the low level of scientific irrigation knowledge of farmers. The factors relating to these problems and possible solutions

are also discussed. It was found that water management between the mogha and the farmers' fields is one of the weakest links in the entire water distribution system. The need for massive improvements both in distribution of the water and in utilization of the water is obvious and emphasizes the necessity for a massive farmer education program conducted by well trained active water management extension field staff. This document presents one proposal for developing such a staff but alternative methods exist that may be just as effective. Until such an on-farm water management extension staff is actively assisting farmers, increases in quantity of water delivered to the mogha from dams such as Tarbela will not provide the benefit to agriculture that their planners and designers envisioned.

Above material in whole or in part found in:
1976 Ann. Prog. Report WMRP CSU, p.791-802.

E-8
Legal considerations and alternatives to organizing water users.
George E. Radosevich. 1976 Ann. Tech. Report WMRP CSU, p.725-752.

This paper is a synthesis of information and experience based upon research and consulting in numerous countries on the subject of water law and water user associations. The importance of local water user organizations is emphasized. General summaries of the structures, functioning and problems of water law in several areas of the world are presented. The paper concludes with a general discussion of factors affecting the effectiveness of local water user associations.

E-9
First training course for water management extension officers at University of Agriculture, Faisalabad. Qurban A. Awan, Norman S. Illsley, W. Doral Kemper, Dwayne G. Westfall and Gaylord V. Skogerboe. 1978 Ann. Tech. Report WMRP CSU, p.558-601.

Under the On-Farm Water Management Pilot Project, Colorado State University has the responsibility to serve as advisors for the training of the Water Management Extension Officer (WMEO), officially titled Agricultural Officer, on the field teams. The University of Agriculture at Faisalabad was assigned the responsibility of training the WMEO. The first course was conducted from June 10 - October 20, 1977. Sixteen persons graduated from the course. All Provinces were represented.

The course is an interdisciplinary course taught by professors from the Departments of Irrigation and Drainage, Rural Sociology, Agronomy, Farm Management, Agricultural Extension, Farm Power and Machinery and Soil Science. The main objective of the course is to teach the WMEO how to work with farmers to get him to clean and maintain their watercourses and adopt new and improved irrigation and cultural practices that will result in increasing agricultural production. The course involves both classroom and field training. The technical skills taught included watercourse improvement and design, water cleaning and maintenance, surveying, measurement of watercourse conveyance efficiency, agronomic production practices for all major crops, operation and maintenance of tractors and implements, precision land leveling and improved irrigation practices. A major emphasis was also given to the socio-economic relationships of improving irrigation practices and agricultural production. Problems encountered in administration of the first course and recommendations for future courses are also outlined.

E-10
Sociological analysis for irrigation water management -- a perspective and some analytical approaches to assist decision making.
David M. Freeman and Max K. Lowdermilk. 1978 Ann. Tech. Report WMRP CSU, p.702-737

The key to improving management of irrigation water is to develop more effective organization. Six major varieties of water management problems are identified based upon two properties of water management

related technology - its divisibility and its private-collective nature. For the types of problems where building or modifying small scale local level organizations, it is hypothesized that in order to be successful one must choose social environments having low conflict polarization, a high percentage of persons with, and a relatively equal distribution of, power and influence. Analytical approaches to identify these are suggested on a preliminary basis based on research on watercourses in Pakistan.

E-11
Farmer organization to improve and maintain watercourses. W. D. Kemper. 1978 Ann. Tech. Report WMRP CSU, p.614-617.

This paper, a talk presented to On-Farm Water Management Project trainees, discusses the importance of instilling in farmers the understanding from the beginning that the program is theirs not the Government's. The specific responsibilities of the watercourse executive committee are listed and the method of initially approaching the farmers discussed. The role of the Government worker should be "advisory" and not "officious".

E-12
Social and organizational factors for farm irrigation improvements: A case study. Max K. Lowdermilk, David M. Freeman and Alan C. Early. 1978 Ann. Tech. Report WMRP CSU, p.673-687.

The kinds and quality of local organizations which farmers create and maintain for the social control of irrigation water intimately affect the efficiency of its use. This paper describes the importance of farmer organizations and farmer participation for the improvement and maintenance of farm irrigation conveyance systems in Pakistan. First, the paper describes the consequences of almost 80 years of being neglect of the farm irrigation subsystem. Second, the importance of understanding and utilizing indiginous forms of collective action for designing and implementing improvement programs once acceptable technologies are made available is discussed. Third, the need for continuous evaluation and improvement of local organization is stressed. The paper also stresses the importance of a systematic, multi-disciplinary approach to identifying and solving water management problems.

E-13
Farm irrigation constraints and farmers' responses: comprehensive field survey in Pakistan. Max K. Lowdermilk, Alan C. Early and David M. Freeman. Water Mgmt. Tech. Report No.48 WMRP CSU, 1978. 158p.

This volume summarizes the findings of the six volume study, "Farm irrigation constraints and farmer's responses, comprehensive field survey in Pakistan". The purpose of the study was to answer a major question, "What are the significant farm level constraints confronting farmers in their irrigation systems which are presently responsible for low crop yields and crop production?". As a problem identification field survey, the goal is to describe how farmers respond to selected constraints as they manage irrigation water for their crop production systems.

The findings are based upon a sample more fully described in Volume VI, Appendix I, Part A. Data were collected during 1975 and the winter-spring months of 1976 on a sample of 3[illegible] farmers located in 16 villages and 40 watercourses stratified by head, middle and tail location. The research sites were selected so as to represent the major agro-climatic zones of the Pakistan Punjab and Sind, but because of USAID's emphasis on the small farmer, the sample includes a disproportionately large sample of villages characterized by small farmer owner-operator majorities.

Chapter I sets forth major findings related to the irrigation system: delivery to the farm, field application efficiency and irrigation efficiency; agronomic factors: crop yield per acre, cropping patterns, intensities; and farmers' perceived constraints with regard to economics, knowledge of agricultural practices, water codes and regulations, and farmer organization. Each of the findings is followed by one or more policy implications.

Employing base-line knowledge gained from the survey, Chapter 2 describes possible criteria--physical, economic and social--to be considered in the selection of watercourse commands for comprehensive improvement of water management in Pakistan.

Chapter 3 discusses implications of subsequent projects, survey and/or implement improvement programs, in terms of delivery efficiencies and application efficiencies.

Appended to the text of this volume are glossaries which include photographs taken in Pakistan during the survey, English and Urdu/Punjabi terms.

Overall the structure of the report which follows in the subsequent five volumes is:

Volume II: States research objectives and describes major features of the irrigation system being studied--rivers, canals, moghas, watercourses, tubewells, and the organization of village social networks.

Volume III: Establishes the consequences of the existing irrigation system, a major one being low agricultural productivity in a part of the world which has potential to be one of the most productive regions on this planet.

Volume IV: Examines major constraints confronting farmers within the existing system which are associated with the low productivity discussed in volume III.

Volume V: Presents farmer responses to the constraints detailed in Volume IV.

Volume VI: Contains supplementary appendix materials relating to methodology, data summaries, watercourse profiles and maps.

Above material in whole or in part found in:
1976 Ann. Tech. Report WMRP CSU, p.578-617.

E-14

Organizing farmers to improve irrigation water delivery--The problem and prospects for solutions in Pakistan. Max K. Lowdermilk, David M. Freeman, Alan C. Early, George E. Radosevich, W. Doral Kemper and Ashfaq H. Mirza. 1978 Ann. Tech. Report WMRP CSU, p.602-613.

This article presents data revealing the extent and significance of losses from watercourses and the benefits of improving watercourse efficiencies for increasing agricultural production and reducing waterlogging and salinity. The key to improving the efficiency of on-farm water delivery is effective organization of the water users.

The main factors identified by various studies as affecting the ability of farmers to organize themselves are listed. Three options, requiring careful testing and research, for organizing farmers are discussed: 1) informal organization; 2) organizing formal associations under the Companies Act (1913); and 3) organizing formal associations under the Cooperative Societies Act (1925). The importance of research systematically evaluating these alternatives is emphasized.

Above material in whole or in part found in:
1976 Ann. Tech. Report WMRP CSU, p.753-772.

Cross References

Additional information related to this subject may be found in the following publications.

B-13, B-14, B-15, F-6, I-11, I-14.

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F. ECONOMIC FACTORS IN WATER MANAGEMENT

F-1
The economics of water use: an inquiry into the economic behaviour of farmers in West Pakistan. D. Worku. Ph.D. dissertation. 1971 Colorado State University.

This report concludes that farmers in West Pakistan are quite sensitive to economic policies. The study argued that the tendencies to overwater or to underwater crops may be explained by the existing water pricing mechanism where acreage rather than the volume is the basis for the water charges.

F-2
Rural labor in Punjab, survey report. Jerry B. Eckert, M. A. Badar, M. Akbar and M. Mansha. 1972 Planning & Development Department, Government of the Punjab, Lahore, Pakistan.

This survey is concerned with determining major rural occupations in selected districts of the Punjab. An attempt was made to determine the impact of the labor transitions underway and to identify key points at which policy leverage might be exerted. The formulation of a rural labor strategy required an accurate and detailed stratification by occupations of the labor force. A determination was made of the primary beneficiaries of employment programs. A careful assessment of the several linkages determining the quantity and source of labor was made. Finally, an analysis was made of the types of changes presently underway with respect to rural employment.

F-3
Private tubewell numbers in Pakistan: a synthesis. Jerry B. Eckert. Pakistan Development Review XIII (I) 13. p.94-105, 1974

Combining information from 6 sources, Eckert shows the growth in number of private tubewells in Pakistan from 1954 to 1972. In that period, the number of tubewells increased from 1,216 to 99,025 in Punjab alone. In Pakistan, they increased from 1,300 in 1954 to 94,638 in 1970.

F-4
Economics of farm mechanization and water development policies in Pakistan: A case study. M. Jamil Khan, Ph.D. dissertation. 1974 Colorado State University 143p.

The purpose of this study was to investigate the relative contribution of selected inputs to farm income, to clarify the interrelationship between various factors on mechanized farms and to determine the income and employment effects of farm mechanization and water development policies in Pakistan. A linear programming model was used to predict the effect of selected public policies and to predict income and employment consequences.

F-5
Economics of improved soil and water management for fodder production in the Shadab. M. Hanif, H. Ali, F. Ali and C. J. deMooy. 1975 Ann. Prog. Report WMRP CSU, p.466-474.

The Water Management Research Sections of the integrated Rural Development Project and Colorado State University in Pakistan are cooperating in a series of practical studies on farmers fields aimed at defining improved agronomic practices for all the major irrigated crops and to introduce the most profitable improvements to the farmer for his acceptance. This paper deals with a first attempt to gain acceptance for improved practices in fodder productions. Demonstration plots with fodder crops of maize and sorghum were laid out on private farmers' land in the Shadab Pilot Project near Lahore. Fertilizer and farm water management improvements were included in the trials. Local

water supply problems minimized the water management inputs for fertilization almost doubled the production of fodder. The cost/benefit ratio of the suggested improvements for maize fodder was 100:647 and that for sorghum was 100:738. These values should carry sufficient weight to motivate the farmer into a change of practice once the new techniques have been introduced to him.

F-6
Socio-economic bench mark survey, Tubewell MN-56. Muhammad Hussain, Barkat Ali and Sam H. Johnson III. Publication No.58 MREP (WAPDA) July, 1976. 27p.

The object of this report is to document conditions related to the situation on the study watercourse prior to the improvement. This was the first earthen improved watercourse and was a cooperative effort between the farmers, Mona Staff and CSU technical assistance. Future reports will document changes that occur with the passage of time.

Above material in whole or in part found in:
1976 Ann. Tech. Report WMRP CSU, p.618-646.

F-7
Cost of water per acre foot and utilization of private tubewells in Mona Project SCARP II. Muhammad Hussain, Barkat Ali and Sam H. Johnson III. Publication No.62, MREP (WAPDA). July 1976. 19p.

The purpose of this study was to explore the cost of production of water from private tubewells, both diesel and electric and to determine how the total water supply available affects the degree of utilization. Data on productive life of different tubewell components as well as data on actual tubewell pumping rates is presented.

Above material in whole or in part found in:
1976 Ann. Tech. Report WMRP CSU, Appendix 18.

F-8
Cropping intensity and water shortages: the response of the Punjabi farmer. Sam H. Johnson III. CSU Field Report No.[illegible]. 1977. 13p.

The object of this paper is to analyze the water management techniques used by the Punjabi farmer to obtain higher cropping intensities. A linear programming model is developed for a typical 500 acre watercourse on a perennial canal in the Sargodha area. The available water is varied to determine the farmers optimum response to different levels of water use.

Above material in whole or in part found in:
1977 Ann. Tech. Report WMRP CSU, p.516-532.

Cross References

A-4, A-5, A-6, A-12, B-2, B-3, B-4, B-5, B-6, B-8
B-9, B-11, B-14, B-15, B-18, B-19, D-8, D-12, D-14
D-20, E-5, E-13, G-4, G-9, H-1, H-4, I-7, I-9, I-10
I-11, I-14, K-1.

G. GROUND WATER HYDROLOGY

G-1

Steady and unsteady flow of fresh water in saline aquifers. D. B. McWhorter. Water Mgmt. Tech. Report No. 30. CSU, 1972. 51p.

Previously developed methods for analyzing problems of flow in aquifers that are saturated with a zone of relatively fresh water over saline water are reviewed. The equations which describe the problem as one of flow of miscible fluids are presented and discussed. It is pointed out that difficulty of obtaining solutions to these equations has fostered numerous attempts to obtain solutions to a more idealized version of the problem. The zone separated from the underlying saline water by a sharp interface. The principle difficulty with the latter formulation is a non-linear boundary condition on the interface between the two zones. The conditions at the interface are discussed in detail. It is shown that interface is unstable under certain conditions. The criterion for interface stability is derived and its practical significance discussed. Various solutions for steady up-coning beneath wells are presented. A new solution to the problem of steady up-coning beneath horizontal tile drains is derived. This solution can be used to calculate the approximate optimum depth to which drains should be placed. Example calculations are given in the appendix. A procedure for estimating the performance of collector wells is discussed.

G-2

Salt water coning beneath fresh water wells. Brij Mohan Sahni. Water Mgmt. Tech. Report No. 18. CSU, 1972. 168p.

Laboratory research was conducted to investigate the phenomenon of salt water coning below a discharge well partially penetrating an aquifer in which fresh water is underlain by saline water. Techniques presently available for analyzing the performance of such wells were evaluated. Both theoretical considerations as well as experimental results have shown that some of the assumptions used in the analytical techniques available are not valid while others are acceptable only under limited conditions. A mathematical model is developed for evaluating the performance of a skimming well under a wide range of field situations. The practical utility of the results in deciding the optimum discharge from a skimming well is discussed. It is shown that for given aquifer conditions and well geometry the maximum steady-state production of uncontaminated fresh water is obtained at shallower well penetrations and closer well spacings than that predicted by the theory previously available.

G-3

Groundwater quality distribution near the Rattokala Distributary-Mona area. D. B. McWhorter. Report to Directorate, MREP (WAPDA), 1973. 12p.

Data collected at Tubewell 39 shows that groundwater begins to get salty at about 90 feet below static water level. Research indicates that optimum penetration of skimming wells is 30 % or less of the thickness of the fresh water zone. A diagram of recommended well construction and salinity levels vs depth are shown. The pumping plant and design would require 2.5 hoursepower to operate the skimming well.

Above material in whole or inport found in
1973 Ann. Prog. Report WMRP CSU, Appendix

G-4

Practical skimming well design. F. A. Zuberi and D. B. McWhorter. Water Mgmt. Tech. Report No. 27 CSU, 1973. 61p.

Well patterns and designs have been investigated in order to compare the technical performance and costs of several possible

skimming facilities. It was established that, for aquifer properties typical in Pakistan, individual skimming wells can be expected to discharge in the range of 0.1 to 0.2 cfs. It is shown that several closely spaced wells can be pumped at a higher total discharge than a single isolated well, even though the individual wells in the battery are discharging at less than capacity. This results from the fact that distributed pumping produces a smaller maximum drawdown than does a single well pumping at the same rate. The discharge obtained by pumping in battery from closely spaced wells (i.e. 10 to 15 feet apart) is approximately 60 percent greater than for a single isolated well. The increased investment for the battery of wells is more than 60 percent higher than for a single well, however cost estimates are contained in the report that indicate a single skimming well will cost approximately Rs. 7000, for comparison. On a per unit discharge basis, the investment in a private tubewell is about Rs. 7000 per cfs and for a skimming well about Rs. 18,000 per cfs. Operating costs for electrically powered skimming wells are estimated to be about 15 percent of the operating cost for a typical private tubewell. On basis of per acre foot of water pumped, a skimming well will provide water at about Rs. 20 per acre foot compared with a cost of about Rs. 13 per acre foot for a private tubewell.

G-5

Saline water pumpage and the "Monsson Flush: as a means for building fresh water storage and reducing salinity, water logging and flooding in the centers of the Punjab Doabs. CSU Water Management Team 1976 Ann. Tech. Report WMRP CSU, p.258-263.

This discussion paper outlines the data needed to evaluate the potential of pumping salt water out of the doabs during the monsoon season which would allow the creation of fresh water storage in saline portions of the doabs in the Punjab.

G-6

Summary report of field observations and site location on the skimming well project. W. D. Kemper. 1974 Ann. Prog. Report WMRP CSU, p.182-185.

Tubewell water salinity versus depth values are shown for three wells in the MREP (Mona) area. Salinity, generally, increased with depth from 1200 ppm at the top to about 4000 ppm at a 100 foot depth. Results of pumping showed that, by lowering the pumping rate from 0.9 cfs to 0.3 cfs, salinity was reduced from 2300 to 770 ppm.

G-7

Wells for skimming fresh water from aquifers with saline waters at greater depths. D. B. McWhorter and W. D. Kemper. 1975 Ann. Prog. Report. WMRP CSU, p.308-324.

Preliminary results of research investigations by CSU are presented along with methodology. Early results of field testing were encouraging and indicated that the fresh water-saline water interface could be controlled and effective skimming wells could be designed. Formulas are presented for determining optimum well penetration and critical discharge for skimming wells.

G-8

1976 skimming well report: field studies. D. B. McWhorter, W. D. Kemper and M. Jenangir. 1976 Ann. Tech. Report WMRP CSU, p.237-257.

An interceptor well placed below a main well was pumped at rates up to 36% the rate of main well discharge but was not effective in keeping the saline cone down or in keeping salinity of water within acceptable limits.

The water table draw down, saline-fresh water interface coning and elementary hyradulic considerations show that most of the water pumped from the fresh water layer (saline water less than 100 feet deep) is replaced by saline water moving upward rather than by lateral transmission of fresh water.

Field studies showed that, for recharge purposes, recharge would need to be localized within about a half mile of where the water is to be pumped from the aquifer.

G-9

Potential for building and utilizing fresh water reservoirs in saline aquifers. W. D. Kemper, Mian M. Ashraf, Maina Chaudhry and S. H. Johnson, 1978 Ann. Tech. Report WMRP CSU, p.460-490.

Deep, high capacity (2 to 4 cusecs) wells in the middle doab areas cause a cone of depression and an intrusion of saline water from below. Relatively shallow (60 to 150 feet) wells of low capacity (.5 to 1.5 cusecs) are producing water of acceptable quality. Skimming wells could be useful in maintaining a low fresh water-saline water interface while lowering the overall water table and creating a reservoir for more recharge. Cost-benefit ratios for water skimming are estimated at 2.1. Costs of ground water storage are estimated at 2.1. Costs of ground water storage are estimated at 10 % of the cost of surface water storage. Graphical analysis of 1976 research on water quality changes due to various pumping schemes is presented and discussed. Three alternate schemes involving fresh water skimming and saline water pumping are presented.

G-10

Utilizing irrigation seepage for groundwater storage. Tom Trout and J. O. Reuss. Field Report No. 8 WMRP CSU, August 1978. 14p.

A mass balance analysis is made of the surface and groundwater hydrology of a watercourse command area to determine the effect of increasing irrigation efficiencies upon the availability of groundwater for pumpage. The study, after demonstrating the extreme inefficiency of pumping supplemental water into a system with high water losses, concludes that even the best earthen watercourse improvement will not endanger the groundwater recharge supply.

Cross References

Additional information related to this subject may be found in the following publications.

I-14, K-16.

H. PRECISION LAND LEVELING

H-1
The economics of land leveling. Bashir Ahmad and Ronald L. Tinnermeier. 1974 Ann. Prog. Report WMRP CSU, p.410-432.

This report analyzes the feasibility of land leveling in terms of costs and returns. Thus, the more valuable the crop the more worthwhile precision land leveling becomes. The authors conclude that land leveling can contribute substantially in increasing yields and in saving water and labor. But, before making an investment in land leveling, returns from other alternative investments must be examined, particularly investments in plant protection measures, fertilizers, tubewells and other modern inputs.

H-2
Improved water and land use management through precision land leveling. Arshad Ali, Wayne Clyma and Alan C. Early. Presented at the International Conference on Waterlogging and Salinity. Lahore, Pakistan, October 1975 61p.

Farmers in Pakistan use the level basin system of irrigation and expend considerable effort in attempting to maintain the level of their fields. Measurements of individual fields in Pakistan have shown that frequently the fields are not level and much wastage of water results caused by excess water application and other management factors. An analysis of these factors is given from observations of the hydraulics of water application to level basins. Data from irrigation of leveled borders are presented to show the improvement in control of the amount of water applications. The procedure of land use improvement through precision land leveling is described. The saving in water will improve yields on existing cultivated land permit increasing the area under cultivation, and reduce salinity and waterlogging.

Above material in whole or in part found in:
1975 Ann. Prog. Report WMRP CSU, Appendix 33, p.410-432.

H-3
Irrigation practices for traditional and precision leveled fields in Pakistan. Wayne Clyma and M. Ashraf. CENTO panel meeting on the optimum use of water in agriculture. March 1975. 35p.

Irrigation practices were studied for both supplemental and unsupplemental water supplies at Mona, Shadab, Mian Channu, Multan and Faisalabad. Results showed that, in general, the median application in supplemental areas exceeded that of the unsupplemented. Three examples on the effects of seasonal irrigation practices on wheat were discussed. Evaluation of fields after leveling showed water savings of 1/3 to 1/2 as compared to traditional fields. Improvements were noted in stand, growth, and fertilizer efficiency. These factors suggest that farmers with short water supplies should reduce their irrigation unit size and precisely level their fields.

Above material in whole or in part found in:
1975 Ann. Prog. Report WMRP CSU, Appendix 32.

H-4
The economics of precision land leveling in Pakistan. Sam H.Johnson III, Ch. Mohammad Hussain, Zahid Saeed Khan and Ch. Barkat Ali. ESSO Seminar on Farm Water Management. Lahore, Pakistan. 1977. 20p.

This paper identifies the economic and physical benefits attributable to precision land leveling. While the work is specific to Pakistan the implications are relevant for other arid areas of the world where irrigation is practiced.

Above material in whole or in part found in:
1978 Ann. Tech. Report WMRP CSU, p.501-515.

H-5

Land leveling and watercourse improvement for Pakistan.
Muhammad Siddique Shafique. M.S. Thesis. 1977. Colorado State University. 99p.

In this study, the research was conducted on the benefits of land leveling and watercourse improvements. For this purpose the Kanjra watercourse command area, near Lahore, was selected. About 20 percent of the area was precisely leveled to determine the seasonal impact of land leveling on application efficiencies. Water measurements were made with cutthroat flumes to determine the differences in delivery efficiency before and after improvement. Economical "katcha" watercourse improvement alternatives were used and the benefit cost ratios always exceeded unity against three selected rates of return. The role of water user associations for implementation and efficient use of water was discussed. Recommendations were made for a package of land leveling and watercourse improvements for Pakistan.

Cross References

Additional information related to this subject may be found in the following publications.

B-3, C-15, E-3, E-9, E-13, I-5, I-6, I-7, K-10, K-12.

I. WATER MANAGEMENT SYNTHESIS AND POLICY

I-1
The problem of under-irrigation in West Pakistan. G. Jones and R. Anderson. Journal of Rural Development and Administration, Vol IX No.2, April 1972 53p.

Widespread under-irrigation is a major constraint on Pakistan's agricultural development. Substantial redesign of Pakistan's irrigation system, which would require large capital investments, will be necessary to provide the farmer with sufficient and timely supplies of water. Regardless of the future development of the Indus Basin irrigation irrigation system, more attention must be given to better utilization of water by the farmers in the watercourses.

I-2
Conjunctive use of Indus Basin Waters - Pakistan: A general summary. T. Chaudhry, Ph.D dissertation. 1973 Colorado State University. 308p.

The objectives of this study was to determine the size of the canal system, the surface reservoir, and the ground water pumping facilities such that, when the system is operated optimally, the capital and operation and maintenance costs of meeting the given irrigation water requirements are minimized. The study indicates that the present "use-when-available" supply system could be developed into a "supply-on-demand" system and thereby increasing the efficiency of water use in the Indus Basin.

I-3
Progress report of the water management scheme for the integrated rural development program at Lar and Shadab. W. Clyma, A. C. Early and W. D. Kemper. 1974 Ann. Prog. Report WMRP CSU, p.250-258

The Water Management Program was initiated with the Integrated Rural Development Program (IRD) to learn the problems in implementing a on-farm water management program in Pakistan. A discussion is given on the progress and problems in implementing the program in Shadab and Lar between summer 1973 and fall 1974.

I-4
Optimizing irrigation water management practices in Pakistan. Gilbert L. Corey. 1974 Ann. Tech. Report WMRP CSU, p.259-269.

Colorado State University's water management research experience in Pakistan to date has been to quantify present practices and to theorize what goals ultimately might be met.

We recognize that a serious on-farm water management problem exists and that there are, at least, five good reasons why high priority should be given to improving present practices. 1) The problems of salinity and waterlogging will be solved only by improving the distribution to and use of water on farms. 2) Improved management would make available much of the water which is now wasted. 3) Increased food production will result through increased yields and increased area farmed with the water saved. 4) Water supplied will receive better distribution such that more equal shares will be received by all farmers regardless of the position of their land. 5) Increased yields and increased acreages of production will result in greater employment, larger and more equitably distributed rural incomes.

The following components are suggested for a program to improve on-farm water management in Pakistan; a national land leveling program, watercourse rehabilitation, modification of the warabundi system, a comprehensive coordinated water management research program and improvements in the institutional framework.

I-5
The importance of farm water management in Pakistan. Wayne Clyma and Gilbert L. Corey. Water Mgmt. Tech. Report No.38. CSU, 1975. 28p.

The problems associated with Farm Water Management and possible practices to overcome these problems are discussed. The practices that need to be integrated into the farm water management system in Pakistan are, field reshaping and leveling, watercourse rehabilitation, irrigation scheduling, discharge augmentation by tubewells, water storage on the watercourse, canal regulation for climate and cropping patterns, soil management for moisture control, precision planting, crop cultural practices and maintenance of the irrigation system. The potential benefits and implications of implementation are discussed.

I-6
Improving farm water management in Pakistan. Gilbert L. Corey and Wayne Clyma. Water Mgmt. Tech. Report No.37. CSU, 1975. 32p.

The strengths and weaknesses of the irrigation system are discussed in detail. The problems that appear to be the largest contributions to limiting agricultural production are summarized. Recommendations for improving on-farm water management and subsequently increasing agricultural production are: 1) research program dealing with on-farm water management problems should be developed; 2) Conjunctive use of ground and surface water should be encouraged, 3) a program of precision land leveling should be launched, 4) watercourses should be rehabilitated and 5) rules and procedures for water delivery to farmers should be reviewed.

I-7
Water management alternative for Pakistan: A tentative appraisal. Jerry Eckert, Niel Dimick and Wayne Clyma. Water Mgmt. Tech. Report No.43, CSU, 1975 61p.

This report discusses a number of issues felt important to an effective water management program. The authors first define several characteristic watercourse situations which are most common in Pakistan. Delivery losses based on recent findings are summarized. A second section develops the value of water used for irrigation as a prelude to evaluating the benefits of several possible program alternatives. Subsequent sections discuss or evaluate alternative solutions to current causes of inefficient water use, including watercourse lining, earthen watercourses, precision land leveling and irrigation extension. Finally, there are suggested criteria for selecting project watercourses with high potential payoffs.

I-9
A research-development process for improvement of on-farm water management. Wayne Clyma, Max K. Lowdermilk and Gilberg L. Corey. Water Mgmt. Tech. Report No.47. CSU, 1977. 58p.

A research-development process for rapid improvement of on-farm water management through technology transfer is described. The process focuses on systematic research to identify problems, develop and assess solutions, and implement development programs at the farm level. An interdisciplinary team executes the research-development process with farmers.

The technology transfer process consists of four interrelated phases as follows: 1) Priority problem identification, 2) Search for problem solution, 3) Assessment of solutions, 4) Program implementation.

Problem identification consists of the combination of an interdisciplinary approach with farmer participation to achieve an understanding of system operation. This results in an objective, quantitative definition of priority problems. The interdisciplinary team combines knowledge and experience with systematic research in Phase 2 to develop direct acceptable solutions to priority problems. Applied, adaptive, and evaluative research methods are used under farmer conditions in Phase 3 for the assessment of solutions. These results are used to redefine problems and improve solutions. In Phase 4 an institutionalized developmentprogram is implemented. Trained personnel

use the carefully designed technological package to work directly with farmers to solve farm problems.

Above material in whole or in part found in:
1978 Ann. Tech. Report WMRP CSU, Appendix 35, p.738-750

I-9
Water problems in the Indus food machine. S.H. Johnson III, A. Early and M. Lowdermilk. Water Resources Bulletin, American Water Resources Association, 13(6):1253-1268. 1977.

Examples are drawn from the Indus Basin to explain why on-farm water management problems restrict the output of agricultural products in many LDC's. Data is presented to illustrate the low level of water management knowledge of both the farmers and the extension agents. Both technical and socio-economic factors that prevent the rapid expansion of food production are presented.

I-10
Improving irrigation water management in the Indus Basin.
S. H. Johnson III, W. D. Kemper, J. Reuss and M. Lowdermilk. ESSO Seminar on Farm Water Management. Lahore, Pakistan 1977 22p.

The purpose of this paper was to present data from current research that documents potential benefits from implementing appropriate policies that have tended to restrict the output of agricultural products in many developing countries. These recommendations are not the final and only set of actions, but they represent a tentative set of solutions that are viable given the institutional and socio-economic conditions that currently exist in the Indus Basin.

Above material in whole or in part found in:
1978 Ann. Tech. Report WMRP, CSU, Appendix 30.

I-11
On-farm water management as affected by size of holding and cropping systems. J. O. Reuss and W. D. Kemper. FAO/SIDA Seminar, Field Food Crops in Africa and Near East. Lahore, Pakistan September, 1977. 11p.

This paper is a synthesis of material gathered from various sources, particularly those of CSU WMRP and Pakistani cooperators. A summary of the major points covered would include the following:

Size of operational units and field size significantly affect the amount of watercourse channels required to deliver water to the field. In Pakistan total delivery channels generally exceed 200 ft./acre (150 meters/hectare). Due to the flat topography and poor condition this extensive distribution system typically operates at between 50 and 60% efficiency. If field size could be increased to 2.8 acres (1.5 hectares) at least half of this system could be eliminated.

Improved water management will require better watercourse maintenance and more effective organization to achieve this at the village or watercourse level. Research and extension programs designed to determine the most effective organization and to promote awareness to the need for better organization and maintenance should be a high priority item.

Even though cropping systems have evolved and adapted over a long time we still find that cropping intensitities and production are limited by water availability at critical periods. Water saved through good management is extremely valuable at these times.

I-12
Institutional framework for improved on-farm water management in Pakistan. Alan C. Early, Jerry B. Eckert, David M. Freeman, W. Doral Kemper, Max K. Lowdermilk, George E. Radosevich and Garylord V. Skogerboe. Special Tech. Report CSU, January 1976. 88p.

Sufficient data has been collected and analyzed to define some of the major irrigation water management problems in Pakistan, as well

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as the technologies that could be employed to correct many of these problems. The authoris perceive the most important components of a water management program for Pakistan to be: (a) watercourse rehabilitation; (b) precision land leveling; (c) small tubewells; (d) effective agricultural and water management technical assistance and extension and (e) development of local institutions to insure the effectiveness of the program. The more difficult problems, though, are not in defining the appropriate technologies, but rather, to define the appropriate processes for implementing such technologies in Pakistan.

This report discusses the problems of an institutional framework for implementing a water management program; the impetus being a loan program between the U.S. Agency for International Development and the Government of Pakistan. The collective thinking of many of the CSU Water Management Research Project staff located in Pakistan and on campus, is contained in this report. As water management improvement programs progress, feedback from actual field operations will provide valuable insight for improving the implementation process. Provision for assuring this feedback and evaluation and continued program refinement are an essential part of the implementation process.

I-13
Planning and implementing procedures for contracting agricultural-related research programs in low income nations. M. K. Lowdermilk, W. Clyma, W. D. Kemper and S.A. Bowers. Ann. Tech. Report No.46. CSU, 1978, 93p.

Procedures and guidelines are presented for research contractors and international donor agencies in establishing research projects in low income nations. The major assumptions are: 1) an international donor agency and a specified host country have reached a tentative agreement for a research program related to agricultural development; 2) the donor agency will request a contractor with proven capabilities, technical competence, and experience to consider a contract for the project; and 3) the host country project will be in cooperation with the donor agency mission located in the host country (or a nearby country) with at least administrative approval for initiation of the project. The process is conceptualized in three phases: 1) preliminary contract discussion and tentative agreements; 2) preliminary field investigations; and 3) decision to accept contract and subsequent project planning.

Also, procedures and guidelines are described for implementing an agricultural-related research project in a low income nation. The implementation procedures are described under the three phases: 1) selection and organization of administrators and the research team; 2) formal project implementation; and 3) evaluation of program activities.

Above material in whole or in part found in:
Implementing procedures for research programs in low income countries. Max K. Lowdermilk, Wayne Clyma, W. D. Kemper and Sidney A. Bowers. J. Soc. of Research Administrators April 1978.

I-14
Farm water management in upland areas of Baluchistan. W. D. Kemper, Mazher-ul-Haq and Ahmad Saeed. Field Party Report 1978 110p.

Water losses during delivery from source to the field averaged 24%, about 50% of the Punjab. Reduced delivery loss was caused by watercourses being shorter and having operating water surface levels that are commonly lower than the surface of adjacent lands. Higher cost of water (ranging from Rs.75 to Rs.1200 per acre foot) also causes most of the farmers to take better care of their water.

Value of water also varied with the season, ranging from zero during January and February when some farmers allow karez water to run to the rivers to over Rs.1000/acre foot in the months of May through August. There is a need for storage to save this water from

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seasons when its value is low to seasons when its value is high. Over-irrigation occurs in the average fields by almost 100%. In Karez areas this is caused by lack of farmer control of the rate of delivery of water.

Water management problems of these farmers are many, varied and worth solving. A diagnostic approach is suggested with technicians trained to work with farmers and groups of farmers to identify and develop solutions to their problems. This would require a more flexible development program than the Punjab On-farm Water Management Program. Decisions as to which improvements will be implemented should be based on economic analyses, with improvements initiated only when anticipated benefits exceed costs.

Cross References

Additional information related to this subject may be found in the following publications.

A-4, A-13, C-8, C-15, E-13, G-2.

J. WATER QUALITY AND SALINITY

J-1

Effect of exchangeable sodium percentage, soil salinity and available phosphorus level on the growth of alfalfa and barley in greenhouse experiments. W. R. Schmehl. 1972 Ann. Prog. Report WMRP CSU, 11p.

Two greenhouse experiments were conducted to determine the response of barley and alfalfa to increasing available soil P at three levels of exchangeable Na (10,20 and 40%) and two levels of salinity (EC of 0.26 and 4 mmhos/cm).

For both crops an ESP of 20 had no detrimental effect on growth response to increasing levels of available soil P, nor was % P affected adversely. When ESP was increased to 40, however, growth was greatly reduced and % P increased. Thus, it appears than an ESP to 20 can be tolerated by these crops when grown in a light textured soil, but that ESP of 40 will not maintain good plant growth. With no intermediate data point the highest ESP for satisfactory plant growth can't be determined.

The results confirmed the usual observation that alfalfa is more sensitive to salinity than is barley. Of particular significance to the Pakistan project were the observations that: 1) increasing salinity decreases the plant availability of soil P. Although available soil P by the soil test was unaffected; and 2) higher rates of P fertilizer are required for saline soils than for non-saline soils.

J-2

Program for computing equilibrium composition of $CaCO_3$ and $CaSO_4$ systems from irrigation water compositions. Dhanpat Rai and W. T. Franklin. Water Mgmt. Tech. Report No. 29. CSU, 1973. 42p.

A computer program was developed to calculate equilibrium solution compositions in calcareous and gypsiferous systems. The calculations in the program are based upon published solubility products of calcite and gypsum and take into account ion-pair formation and the solubility enhancement of calcite resulting from the presence of Mg^{++} and $SO_4^{=}$ in the solution. For a given pre-equilibrium solution, the program predicts equilibrium ionic strength, ionic activity coefficients, dissociated (free) ion-pairs, total concentration of solution species, amount of $CaCO_3$ precipitated or dissolved at a specified partial CO_2 pressure, and the amount of gypsum precipitated. Lime and gypsum solubility results predicted with the computer closely agree with published experimental results. The program is suitable for assessing the sodium and salinity hazards of marginal quality waters using other independently developed parameters, such as the concentrating effects taking place in the soil solution due to evapotranspiration during the cropping cycle and partial CO_2 pressures developed under particular soil and cropping conditions.

J-3

Water quality improvement and gypsum solubility. William T. Franklin 1973 Ann. Prog. Report WMRP CSU, Appendix "F". 18p.

Methods of improving the quality of high-salt and high-SAR waters by blending with better quality water and by adding gypsum are discussed. Blending formulas which can be used to calculate resultant or desired qualities from mixing two or more different quality waters are given. Methods of calculating the amount of gypsum to apply in water to lower the SAR to a desired level are presented. The results of gypsum solubility studies with gypsum particle sizes ranging from 2.D - 0.05 mm (10 - <300 mesh) in a mechanical shaking experiment simulating turbulent flow and in two different-textured soils are reported.

Precise control of calcium concentrations necessary to lower SAR to specific values should be obtained with <0.25 mm (<60 mesh) gypsum metered in flowing water. Coarser sizes, which could be

placed in cross sections of ditches, exhibit sufficient solubility to be useful for reducing the water SAR. Solubility rates and calcium concentration levels in soil solutions can be controlled to a considerable degree by mixing gypsum particle sizes >0.5 mm (>35 mesh) in the soil and, thus, is an alternative method for reducing water SAR. Dissolution of <0.1 mm (<140 mesh) gypsum in soil was comparable to previously published values. For the purpose of removing exchangeable sodium in soil reclamation, the application of gypsum particle sizes greater than about 100 mesh would significantly reduce gypsum dissolution efficiency.

J-4

The effect of water quality on the yield of field crops and chemical characteristics of the soil. C. J. deMooy, H. M. Bhatti, A. A. Chemma, M. Khalid, M. Rafiq, W. R. Schmehl and W. T. Franklin. 1974 Ann. Prog. Report WMRP CSU, p.283-303.

A field experiment with four water qualities and three leaching fractions in factorial combination was conducted for three years to relate crop yields to soil chemical conditions. It was found that the poorest water quality used converted the soil into a saline/alkali soil to a depth of approximately 12 inches. Noticeable increases in salt concentrations occurred to the 5 foot depth and some raise in alkali to a depth of 2 feet. Under these conditions, yield losses of berseem and other fodder crops amounted to 25 to 29 %. The salinity and sodium adsorption ratio of the soil were roughly linearly related to the quality of the irrigation water used and lend themselves to quantitative interpretation. Neither yield losses nor chemical deterioration showed a progressive trend despite continual input of salts with the irrigation water. This suggested that the environment exerted a balancing effect at least temporarily and under the conditions of the experiment.

Above material in whole or in part found in:
Progress Report Water Quality Experiments, Lyallpur.
C. J. deMooy, H. M. Bhatti and A. A. Chemma. 1973 Ann. Prog. Report WMRP CSU, Appendix "I", 11p.

J-5

Effects of soil and water salinity on mini-milo yields. Ghulam Hussain and W. T. Franklin. 1974 Ann. Prog. Report WMRP CSU, p.309-313.

A hybrid sorghum variety, NK Mini-Milo 54BR, was grown to determine the effects of different levels of irrigation water salinity and soil salinity on yield characteristics. As the soil solution conductivity and saturated paste conductivity (EC_e) increased grain, stoves and total dry matter decreased linearly. A "critical" ECe of 2.3 mmhos for a 10% grain yield decrease was observed in these experiments. This is much lower than the 6.0 mmhos reported in US Salinity Laboratory publications.

J-6

Effect of soil salinity on management of soil fertility in saline soils. M. B. Malik and W. R. Schmehl. 1974 Ann. Prog. Report WMRP CSU, p.308.

Significant yield responses to the application of N and P fertilizers to saline soils was obtained. It was estimated that field response to N and P fertilizers on nutrient-deficient soils would be economical to a soil salinity of about 10 mmhos. The relative response to P on soils low in available P was about the same for saline as for non-saline soils with an indication that higher levels of fertilizer P may be needed for maximum production on saline soils. There was no indication of a depression in yield from the application of very high rates of P fertilizer. Although yield responses to fertilizer N are obtained on N-deficient saline soils, excessive rates depressed plant growth, especially at higher salinity levels and with decreasing levels of available soil P. The poor seedling emergence observed for corn and sorghum planted in saline-sodic soils could be improved by the application of P fertilizer.

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J-7

Dissolution rate of gypsum in flowing water. W. D. Kemper, J. Olsen and C. J. deMooy. Soil Sci. Soc. Amer. Proc. 39: 458-463, 1975.

Dissolution rates of gypsum were measured in water flowing through beds of gypsum fragments as affected by fragment size, solution velocity and initial concentrations of Ca^{++} SO_4^{--} and CO_3^{--} in the flowing water. Equations were derived to describe the rates of dissolution and a dissolution coefficient was defined which is a function of fragment size and solution velocity. Rates of dissolution are high enough to distribute quantities of gypsum, which are within economic reach of the farmer, on farm lands via the irrigation water. Sample calculation are made to show how these data may be used to design watercourse cross sections for applying given levels of gypsum to the flowing water.

Above material in whole or in part found in:
1973 Ann. Prog. Report WMRP CSU, p.1-18.

J-8

Use of gypsum stones to lower to sodium adsorption ratio of irrigation water. Bashir Ahmad, W. D. Kemper, Ghulam Haider and M. A. Niazi. 1976 Ann. Tech. Report WMRP CSU, p.565-577.

By lining a short length of a watercourse with gypsum stones the SAR of low quality tubewell water was improved substantially. Gypsum stones 5 to 20 kilograms in size will supply the Ca^{++} needed to bring down the SAR in sodic tubewell waters. The dissolution rate of the gypsum stones was proportional to the square root of the velocity of flow through the bed. Consequently, the increase in concentration of Ca^{++} is inversely proportional to the square root of the velocity of flow, and the size of the stones in the bed. Equations were developed to make the necessary estimations to design channels of the proper cross-section and length to supply the needed amounts of Ca^{++} to the water when the average size of the stones, the low rate of the water, and the initial ionic concentration of the water are known. Procedures for using this technique to improve irrigation water quality are outlined.

Above material in whole or in part found in:
1974 Ann. Prog. Report WMRP CSU, p.304-308.

J-9

Effects of excessive magnesium in irrigation water on wheat and corn growth. W. T. Franklin and J. S. Olsen. 1976 Ann. Tech. Report WMRP CSU, p.66-74.

Greenhouse experiments were conducted with wheat and corn to determine the magnesium (Mg) concentration levels or Mg:CA (calcium) ratios at which growth depression takes place. Wheat yield depression was initiated when Mg in the soil solution was greater than 55-65% in relation to Ca+Mg. High levels of Mg and increasing salinity levels stimulated tiller development, consequently straw yields were not decreased except for the 100% Mg treatment. The corn dry matter production was also not significantly effected by increasing salinity except for the 100% Mg/Ca+Mg water at E.C. = 6m mhos/cm. Plants were not allowed to mature so grain yields were not determined.

Above material in whole or in part found in:
1975 Ann. Prog. Report WMRP CSU, p.120-126.

J-10

Irrigation water quality evaluation under Pakistan conditions. Ghulam Hussain. Ph.D. Dissertation. Colorado State University, 1978. 160p.

A study on irrigation water quality utilized results from three related investigations; a lysimeter study, a field study and theoretical investigations on residual sodium carbonate (RSC). The

purpose was to determine water quality effects on soils and crops in order to recommend appropriate changes in the water quality guidelines in Pakistan.

Results indicated that RSC is not a valid criteria in determining its effects on soils and crops since its effect is confounded with that of the Ca/Mg ratio. The sodium adsorption ratio (SAR) of water was found to be more closely related to the final electrical conductivity of the saturation extract (ECe) and SAR of soil than was the EC of the water. Change in the SAR of the soil, as predicted by chemical equilibrium due to change in CO_2 partial pressure, was relatively small for water containing significant Mg. However, changes due to leaching fractions were substantial. Among the various alkalinity indexes investigated, RSC using only calcium (RSCC) was the most effective in predicting the Ca content of equilibrium soil solution followed by RSC and total alkalinity. If waters are generally low in Mg, RSCC and RSC are essentially the same, but with high Mg waters they are not.

The following recommendations are based on these results. 1) The RSC criteria for water quality evaluation should be discarded. If alkalinity is to be considered, the RSCC criteria should be used instead of RSC since it is a better index for predicting final Ca concentration of the equilibrium soil solution. 2) The analytical procedure followed for determination of total (Ca + Mg) should be replaced by methods which will accurately determine both Ca and Mg in the soil saturation extract. Because many of the ground waters in Pakistan are high in Mg, there is a possibility that Mg saturated soils might develop.

Above material in whole or in part found in:
Criteria for irrigation water quality. Ghulam Hussain and J. O. Reuss. 1976 Ann. Tech. Report WMRP CSU, p.532-544.

Cross References

Additional information related to this subject may be found in the following publications.

D-2, D-8, D-12, G-3, G-5, G-6, G-7, G-8.

K. FIELD METHODOLOGY

K-1
The importance of farm water management in Pakistan. Wayne Clyma and Gilbert L. Corey. Water Mgmt. Tech. Report No.38. CSU, 1975. 28p.

A combination of events have resulted in intensive studies and major programs related to irrigation water management in Pakistan. These studies have all emphasized the necessity of controlling waterlogging and salinity and of increasing irrigation water supplies. The rationale on which all these studies have been based is that most (63 to 85 percent) of the water delivered to the canal outlet (mogha) is stored in the farmer's field and used by the crop. Studies over the world have suggested that such efficiencies may average nearer 40 percent and will frequently be lower.

Data from field observations of farmer practices and watercourse losses in Pakistan suggest that in SCARP areas this efficiency may average as low as 12 percent. Thus, there is great need in Pakistan for a program to improve on-farm water management in order to repress waterlogging and salinity as well as to provide more water for increased crop production. A number of practices that will improve on-farm water management are suggested.

Above material in whole or in part found in:
1974 Ann. Prog. Report WMRP CSU, p.143-161.

K-2
The installation and use of cutthroat flumes for water measurement. Methodology Series No. one. Waryam Ali Mohsin, Wayne Clyma and Alan C. Early. 1975 Ann.Prog. Report WMRP CSU, p.258-271.

A considerable amount of work has been done on the development of water measuring devices including flumes, weirs and flow meters. The latest in the series is the cutthroat flume. The cutthroat flume has certain beneficial operating characteristics including: water measurement is satisfactory under both free and submerged flow conditions and head loss through the flume is low, even less than the long-used Parshall flume. In summary, it gives satisfactory accuracy for water flow measurement in the flat gradient channels of Pakistan. Furthermore, it is easy to construct because of the flat bottom required. Due to the above mentioned advantages, the cutthroat flume should be widely accepted and used by all who are involved in water management work in the flat-gradient channels of Pakistan.

K-3
Measuring tubewell discharges by the Purdue coordinate method. Methodology Series Number Two. Tom Trout and Alan Early. 1975 Ann. Prog. Report WMRP CSU, p.272-275.

This paper describes how the Purdue Coordinate Method can be adapted for us in measuring tubewell discharge rates in Pakistan. The method is applicable when the tubewell discharge flows freely, the outlet pipe is straight for a distance of at least six diameters and is horizontal, and the end of the outlet pipe is round and accessible.

K-4
Soil moisture determination using touch and feel method. Methodology Series Number Three. Alan Early and Wayne Clyma. 1975 Ann. Prog. Report WMRP CSU, p.96-99.

Practical field determination of soil moisture content is a technique that can be very useful to the agriculturalist who applied the irrigation water and the engineer who evaluates irrigation application efficiencies. One method of such field determination has been labeled in Pakistan as the "Touch and Feel" approach and is an adaptation of the method presented by J. L. Merriam. This approach is not meant to replace field samplings and laboratory techniques, but is intended to supplement these techniques when a practical quick estimate is needed.

K-5
Gravimetric soil moisture determinations in the field using the sun drying method. Methodology Series Number Four. A. Early, W.D. Kemper and Ch. Moh'd Hayat Khan. 1975 Ann. Prog. Report WMRP CSU, p.100-104.

For the field worker, an electrical outlet and oven is not always available to dry a sample for the gravimetric method of soil moisture determination. An alternative procedure for drying the samples is to use the sun's energy, which is so abundantly available in Pakistan.

The procedure developed calls for the use of plastic sheets, or the same plastic bags in which the samples are stored, as the container to be exposed to the sun after the first weighing of the sample. The procedure of this step is to spread the sample out and break any clods present for maximum surface exposure to the sun and hence to minimize the required exposure time.

K-6
Soil moisture sampling and calculation using a king tube sampler. Methodology Series Number Five. Alan C. Early. 1975 Ann. Prog. Report WMRP CSU, p.105-107.

The king tube sampler can be a useful tool to the water management specialist in Pakistan. The tube, if properly constructed, and when correctly utilized, can provide volumetric samples of soil to calculate dry bulk density, as well as the soil moisture percentages. However, the extremes in soil moisture condition limit this procedure. In very dry soils, some of the sample is often left in the hole and the dry bulk density is biased too low. In very wet soil conditions, some of the sample is often left inside the tube, also biasing the determination downward from the true value.

K-7
Instructions for meteorological observations: Water management research: A demonstration guideline. Alan C. Early. 1975 Ann. Prog. Report WMRP CSU, p.127-130.

A small meteorological station to make observations of rainfall and evaporation can be a useful tool for scheduling irrigation applications in conjunction with detailed crop and soil moisture observations. This installation is also useful to document climatological events in relation to crop growth stages. The purpose of this guideline is to provide detailed instructions for field workers to measure evaporation and rainfall daily.

K-8
Automatic Rabi drill calibration procedure: An extension guideline. A. C. Early. 1975 Ann. Prog. Report WMRP CSU, p.133-136.

Prior to seeding experimental and demonstration plots, the automatic Rabi drill requires calibration. This is due to the difference in texture and granular structure of the various fertilizers available and due to the fact that this is not a precision planter precalibrated at the factory. For these reasons, procedures have been developed that require three replications in order to draw any conclusions regarding the seed rate per acre that will result from a given dial setting. Also, the trial-and-error procedure of successive approximations is used to attain the desired settings for experimental purposes.

K-9
Differential leveling for bench mark survey of the watercourse. Methodology Series Number Six. Wayne Clyma and Alan Early. 1975 Ann. Prog. Report WMRP CSU, p.276-284.

Differential leveling is the process of finding the differences in elevation of any two points. It usually requires several setups of the instrument along a general line between the two points. Each setup requires a rod reading on a point of previously determined elevation and a rod reading on a point of unknown elevation. A bench mark survey is conducted to provide a widely spaced series of points (pucca nakkas, culverts, bridges, etc.) of known elevation from which a topographic survey is conducted at a later date.

K-10
Field and watercourse orientation mapping using plane table and peep-sight Alidade. Methodology Series Number Seven. Wayne Clyma and Alan C. Early. 1975 Ann. Prog. Report WMRP CSU, p.286-292

The plane table and alidade are frequently used instruments where lay-out maps are needed of irregular field and watercourse orientations. This offers the advantages of preparing the map while the surveying is done and permits checking the watercourse and field layout as shown on the map with the actual layout. This report describes the instruments and the procedures for using them.

K-11
Profile leveling of watercourse main and major branches. Methodology Series Number Eight. Wayne Clyma and Alan C. Early. 1975 Ann. Prog. Report WMRP CSU, p.293-300.

Profile leveling is the process of determining the elevation of the ground surface at a series of points at measured intervals along a drainage ditch, terrace, waterway, road, or for any other purpose where it is necessary to consider changes in elevation of the ground surface. This report outlines the procedures and equipment to carry out this work.

K-12
Topographic mapping using grid method and level. Methodology Series Number Nine. Wayne Clyma and Alan C. Early. 1975 Ann. Prog. Report WMRP CSU, p.301-307.

Maps are essential to the best farm planning. In addition, maps are frequently the basis for engineering design of farm layouts and soil and water conservation structures and facilities. A map which shows horizontal distances, horizontal angles and elevations is called a topographic map. The addition of elevation to a map results in the map showing topography are relief of the land surface. This report outlines the methods of mapping, procedures to use and application.

K-13
Watercourse survey handbook. Methodology Series Number Ten. Alan C. Early, Max K. Lowdermilk and Wayne Clyma. 1975 Ann. Prog. Report WMRP CSU, p.612-616.

This is a handbook that was prepared for the watercourse survey conducted by CSU in 1975. It contains information on watercourse survey philosophy, major aspects of the survey, the methodology to use in approaching the villagers and a series of questionnaires that were used to collect agronomic, engineering and socio-economic data. It would be halpful to anyone concerned with research, programs and policies related to water management and land leveling projects.

K-14
Procedure for permanent raingage installation. Methodology Series Number Eleven. Alan Early and Waryam Ali Mohsin. 1976 Ann. Tech. Report WMRP CSU, p.229-230.

Long term watercourse studies require the measurement of water inputs to crop production from rainfall. The primary concerns in raingage installation is for security of the equipment and location of the raingage with respect to obstacles. This report outlines the procedure for the preparation of a concrete pedestal and security chain and site selection.

K-15
Procedure for permanent flume installation. Methodology Series Number Twelve. Alan Early and Waryam Ali Mohsin. 1976 Ann. Tech. Report WMRP CSU, p.231-233.

Watercourse studies of long term duration, for an entire cropping season or longer, require frequent measurement of mogha discharge. Intensive studies over time require continuous measurement of

mogha outlet discharge. For these purposes, the permanent installation of a cutthroat flume is recommended with concrete used as a foundation, approach floor and walls. This report outlines the procedures to follow in installing a pucca flume installation and discusses the critical elements of a permanent flume installation.

K-16
Procedure for observation well installation. Methodology Series Number Thirteen. Alan Early and Waryam Ali Mohsin. 1976 Ann. Tech. Report WMRP CSU, p.234-236.

To assess the possible contribution of the water table in meeting the crop needs for water, a record of water table fluctuations over time is required. This report provides instructions to the field engineer for the installation of observation wells for watercourse surveys. One important requirement for the successful operation of observation wells to indicate water table depth is the provision of a pea gravel shroud around the pipe. This is essential for the water table level to be accurately reflected in the measurements.

K-17
Measurement and calibration of mogha outlet discharge using staff gauges. Methodology Series Number Fourteen. M.F.K. Niazi, Nazir Ahmad and A. C. Early. 1976 Ann. Tech. Report WMRP CSU, p.221-225.

Common mogha outlets in Pakistan are masonry orifices, pipe outlets and wooden chutes. They are usually placed at the bed level of a distributary or minor. They may be circular, rectangular or trapezoidal in cross section and may have submerged (outlet under water on the downstream side) condition, or free fall condition. This report outlines the installation and calibration procedures that should be followed.

K-18
Estimation of water losses in watercourses. Methodology Series Number Fifteen. Nazir Ahmad and Alan Early. 1976 Ann. Tech. Report WMRP CSU, p.226-228.

Most of the water loss studies to date have been conducted under conditions where steady state flow could be assumed. Summation delivery efficiencies of water through watercourses are considerably less than those measured under steady state conditions. Losses such as dead storage, infiltration, rodent holes and nakka leaks are involved before the water enters the field. The losses involved in filling dead storage, and infiltration during the early period of watercourse filling, can be estimated as a function of mogha discharge and time required to fill dead storage. Submission delivery efficiencies, E_s, can be calculated by dividing water delivered to the field by the volume of mogha flow. This report outlines the types of losses that are involved and the procedures to follow in calculating delivery efficiencies.

K-19
Directions for application of controlled amounts of water with siphon tubes. John O. Reuss. 1976 Ann. Tech. Report WMRP CSU, p.394-399.

Field measurements have been taken which enabled the calibration of 4.5 ft, 5.5 ft., and 6.5 ft. siphon tubes. Water application can be calculated under three different cases; 1) when the water level in the plot is below the outlet during the complete delivery; 2) when the plot does not initially contain water, but would fill above the end of the siphon outlet during the filling; and 3) when the plot contains water at the start of the application. Graphs needed for the calculation are developed for the three different cases.