ECONOMICS OF LOCAL CONTROL OF IRRIGATION WATER IN PAKISTAN: A PILOT STUDY

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DISSERTATION

ECONOMICS OF LOCAL CONTROL OF IRRIGATION WATER IN PAKISTAN: A PILOT STUDY

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY RAYMOND ZAFAR HANNAN RENFRO

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ABSTRACT OF DISSERTATION

ECONOMICS OF LOCAL CONTROL OF IRRIGATION WATER IN PAKISTAN: A PILOT STUDY

Pakistan's irrigation system is among the world's largest. Government agencies share responsibility for diversion works and delivery canals while management of local distribution networks is left to farmers. Water allocation to farmers is based on rigid weekly schedules designed to be self-policing. The system achieves administrative parsimony at the expense of productivity because rigidity of the supply schedule causes irregularities in supply.

It is recognized that farmers use a variety of activities and transactions to increase productivity by increasing flexibility in both timing and quantity of water supplies. A detailed description of the activities is undertaken, their effects on production are examined, as are the interrelationships of the activities and their possible joint effects on productivity.

A separate but related objective was an evaluation of a program for improving local irrigation ditches jointly operated by farmers. This program was undertaken in response to government estimates that substantial losses of water occur in watercourses. The program, while impossible without farmer support, is not generally locally-initiated.

The locally-initiated activities studied include private tubewells, private trading of canal water turns and flexible water right rotations.

An interview sample of 130 farmers on 20 watercourses was taken in 1981 in the Faisalabad District, Punjab Province. Ten watercourses had undergone the watercourse improvement program, while the balance represented a control sample.

Findings include: (a) use of tubewell water has a strong positive effect on value of crop production; (b) farmers actively trading canal water averaged considerably higher productivity than those who reported little trading; (c) important positive interactions are demonstrated between tubewell water use and trading on productivity, and among all locally-initiated control measures; (d) the watercourse improvement program was not demonstrably successful in increasing either water supplies or productivity; and (e) mean productivity per acre is higher on watercourses with a history of cooperative projects than on other watercourses.

Implications include re-evaluation of the watercourse improvement program, and encouragement of efforts to continue and expand private tubewell use. Any means to increase local private control of water supplies, with minimum government interference, will likely have positive results on productivity.

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To Yasmin,
whose deep love and
fortitude acted as a beacon.

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CHAPTER I

INTRODUCTION AND OBJECTIVES

Pakistan's irrigation system is among the world's largest. Government agencies share responsibility for diversion works and delivery canals while management of local distribution networks is left to farmers. Water allocation to farmers is based on rigid local weekly schedules designed to be self-policing. Rigidity of the supply schedule causes periodic shortages or overabundancies of water supply.

The government estimates that substantial losses of water occur in the canals and largely unimproved local water distribution systems on watercourses. Only in very recent years has attention been given to the local water management problem.

Increased supplies and improved timing of supplies have also been provided by both public and private groundwater development and use of tubewells. However, relatively little attention has been given to locally-initiated alternatives for improving productivity of irrigation water use in Pakistan.

This dissertation is mainly a descriptive study of the warabundi[1] rotation system in Pakistan. From the onset, certain relationships between farmers served as a focus of attention. These included sale or trading of water, the ownership patterns of private tubewells and the

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[1] For definitions of technical or local terms the reader may consult the Glossary at the end of this dissertation.

group cohesiveness of farmers sharing local water delivery ditches (watercourses). In the course of the research another objective was added: an economic evaluation of a governmental watercourse improvement project.

When results of the study were analyzed, it became apparent that a common element linked farmers' interaction with regard to their water supplies: an effort to increase the flexibility of water supply in order to meet urgent, but largely unpredictable, crop water demands. Consequently, analyses of findings are framed with reference to 'methods of increasing control' of water supplies.

Field work reported in this study was motivated by the fragmentary descriptions of water related transactions between Pakistani farmers found in the literature on economics of irrigation in Pakistan. Descriptions are notably lacking with respect to: the watercourse setting; the workings and alternate forms of warabundi; the nature and extent of trading canal water; and the nature and extent of private tubewell water use, in conjunction with canal water supplies. Only watercourse improvement had been studied in some detail, because of its unique project status under the Government of Pakistan's On-Farm Water Management Pilot Project. However, in no prior study was watercourse improvement portrayed as only one of a number of possible methods to obtain added control and flexibility -- i.e., to satisfy crop-water requirements, in response to evapotranspiration and stress conditions, with timely and sufficient supplies of water. This study is particularly interested in this "larger picture," so to speak: the interrelationships between these various local methods or options of control and their effects on productivity.

Flexibility in Satisfying Transient Peak Demand

In order to appreciate the importance of control and flexibility in the use of irrigation water supply it is well to keep in mind the conceptual link between soil, crops and water requirements in relation to temperatures, evapotranspiration, crop stress and consumptive use requirements. Crops will experience periods of severe evapotranspiration and stress in certain periods of the growing season, which will result in sub-optimal yields and production if not satisfied by water applications to root zones.

In economics, this basic concept is often discussed with regard to "peakload demand," as in the example of demand-supply relationships for electricity. Three types of demand are often discussed in this context: (1) base load demand, corresponding to a predetermined minimum consumption level; (2) daily and seasonal peak demand, with a variable base, corresponding to those periods of high (predictable) demand; and (3) transient peak demand, corresponding to shorter periods of extraordinarily high (unpredictable) demand.

The shadow price of water varies in relation to peakload demand and crop stress. Johnson (1978) used a linear programming model of crops and found very high shadow prices for irrigation water in Pakistan correspond to high seasonal peak demand. But these shadow prices are based on monthly water supplies, and Reuss' work (1980) has shown that extreme climatic conditions can cause drastic fluctuations in water demand in periods as short as one week, where crop requirements may exceed canal water and rainfall supplies. These are the "transient peaks" whose shadow prices must exceed those estimated for monthly water supplies (see Chapter IV for detailed discussion of this point).

In the area of Pakistan's Punjab surveyed by this study, canal water undoubtedly provides limited flexibility to farmers in controlling water supplies because of the lack of storage capabilities outside the government-administered dams and reservoirs, with one limited but important exception: water can be stored in the topsoil for short periods of time. Based on a priori knowledge we know that tubewell water acts as demand water, in the sense of supplementing canal water supplies in transient peak demand periods. For the purposes of this study, the marginal value product of tubewell water, as opposed to canal water, provides a proxy of the value of flexible water supply.

Farmer Initiated Methods of Control

Three of the methods for increasing farmer control of water supplies in Pakistan, which are the focus of this pilot study, are "indigenous," in the sense that they are locally initiated and occur more or less spontaneously among farmers sharing watercourses. These methods include private tubewell water use, trading of canal water (warabundi) turns and the practice of "kachha" warabundi on internal watercourses. The reader may find explanations of these Urdu and Punjabi terms in the Glossary and, in detail, in Chapter IV.

Briefly, warabundi (literally, "fixation of turns") gives each farm included in the watercourse command or irrigated area a turn of the total quantity of surface water being continuously discharged through the canal outlet in a sequential downstream pattern –

proceeding from head to tail of the watercourse on a turn-by-turn basis. Turns are allocated in direct proportion to farm acreage size.

Internal watercourses convey (diverted) water from the sanctioned main or primary channel to farms and fields within a block of land known as a "square" or a partial square (a full square is typically 25 acres).

Kachha warabundi (kachha literally means "adjustable," "flexible" or "unsanctioned") is a practice of allocating canal water among multiple users without government interference or involvement. Its antithesis is pakka warabundi which is formally agreed upon by the Irrigation Department, and is always based on a rotation of seven days (receiving a turn once every seven days).

The principal advantage of pakka warabundi is that it minimizes the opportunities for, and frequency of water disputes between irrigators. The primary advantage of kachha warabundi is the potential for flexibility in rotation cycles and scheduling to accommodate the changing irrigation needs of irrigators at different relative positions on either a main or internal watercourse. Pakka warabundi requires each farm to receive a turn at the canal discharge or flow on a weekly basis -- on a specific day each week, and at a specific time of the day or night. Kachha warabundi is a system of loosely fixing turns for each farm based on a cycle of however many days the majority of irrigators concerned deem desirable.

Kachha warabundi on an internal watercourse (i.e., within the "square") implies that irrigators sharing a common "nakka" outlet off the main watercourse mutually agree not to "fix" their respective turns to the full canal discharged flow (in proportion to irrigated land holding) on an exact day of the week and at an exact time of the day, as with pakka warabundi. Instead, these irrigators regularly alternate the order of receiving turns, so that each gets an opportunity to receive the water first among this particular group of irrigators. On the other hand, pakka warabundi on an internal watercourse, implies that an irrigator's (or irrigators') turn is fixed or sanctioned, regardless of whether the turns of other irrigators in that "square" are fixed.

One reason for treating the indigenous methods together is the a priori likelihood that they are interrelated. The availability of tubewell water can decrease the risk inherent in lending or borrowing partial or full turns. Farmers who are able to purchase tubewell water on short notice can more than compensate for partial turns foregone, as the risks of plant stress and willingness to trade are reduced. The practice of kachha "internal" warabundi can also decrease the risk of obtaining timely water on short notice since relatively more ease is possible in adjusting the turns of other fellow irrigators on the same internal watercourse to coincide with own needs. This flexibility is favorable to tubewell water sales and use because unforeseen circumstances may require adjustment of turns on short notice to effectively utilize tubewell discharges.

Watercourse Improvement

The watercourse improvement program is treated separately from the other methods of increasing control (it is the sole focus of Chapter VI) because it is typically not initiated from within the watercourse command and because it is the subject of considerable government expenditure.[2] The process of watercourse improvement is described in detail in Chapter IV.

Conceptually, watercourse improvement, by reducing conveyance losses, increases overall supplies of canal water, with proportionately greatest gains going to tail-end farmers who are most affected by conveyance losses. The overall increase in canal water supply acts to reduce the urgency of need for a flexible supply; and because it reduces the urgency of short-term demand, it potentially increases the willingness of neighbors to relinquish a partial turn.

Objectives and Procedures

The objectives of the study are to describe the organization of water distribution below the canal outlets, to estimate the effects of water control options on crop productivity, to examine interrelationships between these options, and to estimate net returns to both farmers' expenditures and the On-Farm Water Management Pilot Project of watercourse improvement investments with partial lining.

For this purpose a survey of 20 watercourses was conducted in mid-1981 in the Faisalabad area of the Punjab Province of Pakistan, given a population size of approximately 90,000 watercourses throughout Pakistan from which sampling could have occurred. Ten improved and ten unimproved or "control" watercourses were included, and 120 individual farmers at head, middle and tail locations on these were interviewed.

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[2] The On-Farm Water Management (OFWM) Pilot Project, which began in 1976 as a USAID funded project gained full-fledged project status in July 1981 under World Bank funding.

Volumes of both canal (surface) and tubewell (ground) water received at different points on the sampled watercourses were estimated through actual measurements.

The ten sample improved watercourses were randomly selected from OFWM records in Lahore and Faisalabad. The ten control watercourses were then selected with great care from Irrigation Department records in Faisalabad on a paired sampling basis according to certain criteria, as explained in detail in Chapter III.

Because this is a pilot study, with the overall objective of formulating testable hypotheses in the area of local control of irrigation water supplies, attention was given to stratified sampling of farms at different watercourse command positions and different size categories. The stratification of the individual farm sample into relative watercourse positions enabled a close evaluation of the effect of watercourse improvement on tail farms. This stratification results in a non-random sample and therefore findings from this research can not be generally construed to a larger (ill-defined) population, nor to major implications for policy making. Results can, however, be used to suggest important areas for further research.

The statistical analyses used to evaluate the four methods of control include production function estimation through multiple ordinary least squares regression techniques, other regression model estimations and analysis of variance. For reasons mentioned above, and described in more detail in Chapters III and V, significance levels and tests associated with the statistical analysis can be only interpreted in a very limited sense: they apply only to this particular sample and not to a larger population of watercourses or farms.

Based upon production function estimates, marginal value products of all major production (crop-related) inputs are estimated and these are compared to estima[illegible] opportunity costs of use. In particular, cash inputs (notably fertilizer) use is shown to have complementarity with all the control enhancing activities examined. Comparison of OFWM watercourse improvement results, with previous economic studies in this regard, is facilitated by use of a benefit-cost framework of analysis for estimating net benefits accruing to both individual sample farmers and the OFWM project.

The organization of the remainder of this dissertation is as follows:

Chapter II consists of a general review of literature most relevant to this study, including the analytic estimates of the value of water in the Pakistan context, and the four methods of local control examined in detail here.

Chapter III discusses the sampling and data collection procedures used to examine and partially isolate for the effects of watercourse improvement, in particular, but also tubewell water use, trading and the type of internal warabundi.

Chapter IV provides the necessary physical and institutional background information about the canal irrigation system, the different types of watercourses, the warabundi distribution system on watercourses, the different types of warabundi, the procedure of irrigating with private tubewell water, the procedure of trading canal water partial turns, the nature and extent of trading and the process of watercourse improvement.

Chapter V explores the effects on control and crop production of the indigenous, locally-initiated farmer options of tubewells, canal water trading and type of warabundi practiced on internal watercourses. The effects of differences in tubewell ownership patterns and sources of tubewell power are also examined. Production function analyses are used in conjunction with other statistical tests to examine these issues. Economic efficiencies of production function input use are also determined with respect to different sample categories of irrigated farms.

Chapter VI examines the benefits of OFWM watercourse improvement through corresponding production function and other statistical tests, including benefit-cost analysis. The effects of watercourse improvement on relative watercourse (farm) position are also examined through these analytic approaches. Economic efficiencies of production input use are also determined with respect to sample categories of farms considered here.

The final chapter summarizes the major findings of the study and specifies the limitations of the study. Some specific suggestions for further research in irrigation water control and farm management are also included.

CHAPTER II

BACKGROUND AND PREVIOUS RESEARCH

Descriptions of the warabundi system in Pakistan and the nature and extent of both canal water trading and tubewell water sale and use were desired to ascertain their potentials for enhancing localized controls by farmers over uncertain and irregular water supplies. All three control options entail some degree of cooperation and collective behavior. Information on these and other options available to Pakistani farmers was also desired to ascertain their relative impacts on productivity. Some of this information is available in the literature, although both detailed descriptions and empirical results appear to be generally lacking.

Important contributions in the literature helped formulate the theoretical approach to estimation of the value of water to crop productivity. Other sources helped pinpoint the major institutional and technical options for added flexibility in water supplies in Pakistan. These include the type of warabundi practiced on watercourses, trading of canal water turns, private tubewell investments and watercourse improvement. Significant contributions in these respective areas are briefly discussed below. The literature is also notable for its general lack of description and empirical evidence regarding actual patterns of trade and sale in canal and tubewell water, and the different types of warabundi systems.

Analytic Estimates of the Value of Water

Several studies have attempted to systematically provide estimation of the value of irrigation water through both linear programming and production function techniques.

Johnson (1978) used agronomic crop-water response functions to construct cropping activities which allow various degrees of plant stress in order to estimate shadow prices of irrigation water during seasonal peak demand times. Ali (1980) adapted Johnson's model to examine both optimal earthen watercourse improvements and optimal lining through a mixed integer (non-linear) programming technique. Both Johnson and Ali demonstrate that the value of water changes throughout the year in response to predictable seasonal (monthly) peak crop requirements. However, they leave aside the difference between canal and tubewell water in offsetting stress conditions and impacting productivity. The option of obtaining timely supplies of canal water through trading is also not considered.

Khan (1975) used both production function and linear programming techniques to examine the relative values of certain selected inputs to productivity in Pakistan. His results indicate that the contribution of water to farm income was greater than that of any other input. The production elasticity was 88 percent higher than the nearest competitor, cash expense, and far above the other inputs of labor, bullock power and tractor power.

Hussain (1981) used both production and profit function models to examine both allocative and technical efficiencies on different size farms in Pakistan. His results support Khan's finding that water contributes more to farm income than any other input, with a qualification that the estimated production elasticity for water is lower in zones with more saline groundwater.

None of the studies reviewed focus on differences between effects of canal and tubewell water on productivity. Production function studies aggregate water inputs into a single annual supply, while programming studies do the same thing on a monthly basis.

With the exception of Ali (1980), none of the studies make adjustments for watercourse conveyance losses. Results from this study indicate that failure to adjust for conveyance losses leads to significant over-estimation of water application. Flume measurements indicate that the conventional estimation method of multiplying numbers of irrigation applications (the sum of canal and tubewell water applications) by an assumed four and 2 1/2 acre inches per heavy and light application, respectively, inflates total volume applied by an average of 115 percent. Further elaboration of these results appears in Appendix C.

Cooperation and Farmer Organizations

The degree of cooperation on a watercourse can hypothetically relate to the type of warabundi practiced, the degree of canal water trading, cash transactions and use of tubewell water, and whether watercourse improvement takes place. By affecting water input use, and other related inputs, the degree of cooperation affects agricultural productivity. Several studies shed light on these interrelationships in the Pakistan context.

Merrey (1979) found that there are status-related elements of Punjabi values and culture that inhibit farmers' ability to cooperate in locally initiated watercourse rehabilitation projects. In an expanded study on this broad issue, Mirza and Merrey (1979) observe that successful OFWM watercourse improvement and cooperative cleaning and maintenance programs are most likely to occur on watercourses where farmers are relatively equal in status and power, and have a history of cooperation on other community projects (see also Haider, et al., 1979).

Sparling (1980) used the results of Mirza and Merrey to show that the presence of multiple (two or more) private tubewells adequately discriminates between the "previous cooperation" watercourses from the "little or no previous cooperation" watercourses. Furthermore, he conceptually links cooperation to both canal water trading and watercourse improvement, in a three-way interaction. He argues that as watercourse improvement (largely a function of cooperation) reduces conveyance losses and increases overall supplies of canal water available, this increase acts to reduce the urgency of need for a flexible supply. The reduction in urgency of short-term demand tends to increase the willingness of neighboring irrigators to relinquish a partial turn of canal water. Trading is, in fact, an element of overall cooperativeness on the watercourse, but (as will be seen in Chapter IV) on a smaller scale.

Warabundi Allocation Systems

Several sources adequately describe the overall canal irrigation system in Pakistan, including WAPDA (1979), Lieftinck, et al. (1968), Gibb, et al. (1966), Unti (1972) and Lowdermilk, et al. (1978). Few, however, attempt to describe the distribution of water below the canal outlets. The only serious attempts to describe the warabundi rotation system in detail are Nasir (1981) in his interpretation of the Northern Indian Canal and Drainage Act of 1873, in the Pakistan context, and Malhotra (1980) in the similar Indian context.

Malhotra's major conclusion that the warabundi system, in general (and pakka warabundi, in particular), is basically an equitable system, is strongly endorsed by Seckler (1981).

The only published research in the Pakistan context which contrasts pakka and kachha forms of warabundi are those of Mirza, et al. (1975) and Lowdermilk, et al. (1978). Mirza, et al. demonstrate that switchovers from kachha to pakka warabundi in Punjab were mainly due to desires of tail-end irrigators and smaller, disadvantaged farmers to minimize canal water-related disputes and to avoid thefts by, typically, head-enders and larger farmers. Lowdermilk, et al. indicate that the overwhelming majority of pakka warabundi arrangements exist on perennial watercourses in Punjab, and kachha warabundi on non-perennial watercourses in Sind,[3] although the impacts of these differences in warabundi arrangements on productivity were not a major focus of their study.

None of the above-mentioned sources have discussed the type of warabundi arrangements present on internal watercourses. The author believes that the description of kachha internal warabundi is therefore an original contribution of this study. The isolated effects of type of warabundi on either main or internal watercourses on productivity

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[3] Perennial watercourses receive canal water year-round, whereas non-perennial ones receive canal water only during the summer season when river flows are higher.

has not been the focus of any prior study. Nor has any research discussed in detail the link between canal water distribution systems and either canal water trading or tubewell water sales.

Transactions in Canal Water

Many publications deal not only with water distribution under appropriative or rotational schemes, but also with water exchanges and rentals. Gustafson and Reidinger (1971), Burness and Quirk (1979), and Howe, et al. (1981) specifically argue that added flexibility is desirable to maximize social returns, and that the key to added flexibility is the institution of organized water markets.

Gardner and Fullerton (1968) demonstrate through regression analysis that rental prices of water are significantly increased by permitting inter-company transfers in areas of Utah (i.e., free exchange of irrigation water between private companies with storage capabilities and/or rights to stream flows). Water delivery and use per acre are also significantly increased through such transfers. One reason conjectured is that markets decrease the risk of water shortages, which may change production functions upward. Anderson (1961) reached similar conclusions from data analyses of inter-company transfers in northern Colorado.

In the Indian and Pakistani context, Gustafson and Reidinger (1971) argue that water trading and sale should be permitted and made legal, and that the development of some form of water users' associations would facilitate these transactions.

The association could contract with the government for timed delivery of water and then manage internally the problem of allocation among multiple users. It could then auction or sell water available in excess of guaranteed deliveries to farmers, with the profits either shared among the members or perhaps devoted to watercourse cleaning and maintenance. These ideas are reiterated in Reidinger (1980), where allocation through a water users' association is advocated as a replacement for the entire warabundi system.

Maass and Anderson (1978) provide evidence that there are other areas of the world besides the United States where water rights are actively traded or sold. Simulation analyses indicate substantial returns from a type of distribution system with active cash transactions in water rights over other more rigid systems - including rotational ones similar to South Asian warabundi.

Whereas most authors agree that theoretically organized water markets would improve on most, if not all, irrigation water distribution systems in the world, including Pakistan and India,[4] there has been no empirical research done on the net returns of canal water trading and/or sale on productivity.

Tubewell Investments and Water Sale

There have been many reports of the rapid increase in private tubewell investments in Pakistan since the 1960's. Among the most notable are Khan (1975), Johnson (1976), Lieftinck, et al. (1968), Lowdermilk, et al. (1978) and WAPDA (1979).

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[4] The notable exception is Seckler (1981), who while not condemning local water market operation, does not recommend it in his suggestions for improving upon warabundi (p. 27). From his survey of 70 farmers in Haryana, he surprisingly did not encounter any instances of trading canal water turns.

Lieftinck, et al. (1968), Lowdermilk, et al. (1978) and WAPDA (1979) describe the rapid growth in tubewell investments and the enormous potential for tubewell water to supplement scarce canal water supplies. Lowdermilk, et al. cite evidence of active selling activities in tubewell water in their large sample of 40 watercourses, but do not demonstrate either the isolated or joint impact (along with canal water) of tubewells on productivity.

Even Khan (1975) is unable to demonstrate through production function analysis the separate effect of tubewell water use on productivity, because of an inability to separate out the effect of tubewell water from canal water.

Johnson (1976) provides in-depth analysis of the total costs of private tubewells and costs of tubewell water use per acre foot, but does not estimate the effects of tubewell water utilization on productivity.

Watercourse Improvement

The available studies focusing on the economic impacts of OFWM watercourse improvement include CSU and Mona (1977), WAPDA (1979), Gill and Shah (1981), Ashraf (1980), Siddiqui (1981), Khan and Sadiq (1981) and WAPDA (1981).

The detailed study of one improved watercourse in the Sargodha area of Punjab by CSU and Mona researchers (1977) includes some partial benefit-cost analysis based on water flow measurements taken both before and after improvement. Since lack of detailed production data prevented accurate estimation of direct benefits from improvement, these researchers used estimates of benefits from an alternative source of added water supply, tubewells (Eckert, et al., 1975). Using these extremely rough estimates of annual net project benefits, they calculated benefit-cost ratios, assuming a 25-year life of project improvements, ranging from 1.76 (with annual benefits of Rs. 46/acre foot and a 15 percent discount rate) to 4.74 (with annual benefits of Rs. 96/acre foot and a 10 percent discount rate).

A large 61 watercourse survey by WAPDA (1979) includes a supporting report on OFWM activities, but, unfortunately, none of the sampled watercourses were ones improved by OFWM. Nevertheless, the WAPDA report estimates the economic returns to watercourse improvement, making the heroic assumption that net cropped income increases an average of Rs. 500 per acre as a result of improvement. Even so, the calculated benefit-cost ratio is only a dismal 0.85, assuming a discount rate of 8 percent and an expected life of seven years. If the life is extended to ten years, the benefit-cost ratio increases to 1.0, the break-even point.

OFWM Training Institute researchers (Gill and Shah, 1981) observed from a survey of 11 Punjab watercourses improved in 1978, that cropping intensities and per acre yields of major crops rose as a result of improvement. Based on the observed 20 percent increase in cropping intensities alone (they assume a constant net income of Rs. 500 per acre both before and after improvement), a benefit-cost ratio of 3.25 is calculated, assuming a discount rate of 12 percent and a project life of five years.

Ashraf (1980) conducted a detailed study of 180 farmers on 15 improved and 15 unimproved watercourses in Punjab, with farmers interviewed at head, middle and tail watercourse positions. Only preliminary data analyses have been performed by Ashraf to date. Conveyance efficiencies, measured by cut-throat flumes, and cropping intensities appear to be higher on improved watercourses, but by how much is unclear. Average per acre yield data with respect to the two types of watercourses are not provided. Nevertheless, a benefit-cost ratio of 3.1 is calculated for net returns to farmers, assuming a discount rate of 15 percent and a project life of ten years. The internal rate of return is a very high 288 percent. Ashraf then calculates an overall internal rate of return of 13 percent to the OFWM watercourse improvement project. This rate of return is based on calculations which include actual project expenditures and estimates of income generated as adjusted by import (shadow) prices for sugar and wheat, and export prices for rice.

Siddiqui (1981) conducted a survey of 16 improved watercourses in Sind. Sampling was not done on control, unimproved watercourses, but instead use was made of bench-mark data from a Sind provincial government study covering some 622 farms. Results of Siddiqui's study show that average cropped area and cropping intensities have increased as a result of watercourse improvement. Yields of major crops also appear to have increased: percentage differences of 40 percent for sugarcane, 62 percent for wheat and 36 percent for cotton were reported. Gross value of production per acre calculations indicate an increase of 26 percent. However, no statistical tests of significance were performed, making the initial results inconclusive. No cost estimates were made, and no benefit-cost analysis was attempted. Results from Sind may not compare with results from Punjab, due to the great differences in soils, land tenure, irrigation practices, waterlogging conditions, etc.

A recently completed study by Khan and Sadiq (1981) computes a benefit-cost ratio of OFWM watercourse improvements of 2.32, assuming a social discount rate of 12 percent and a life of the project of five years. If the life is increased to ten years, the ratio improves to 2.53. However, this study suffers from very serious data limitations (only 43 total farmers were interviewed on two improved and three unimproved or control watercourses) and a complete lack of randomization in the selection of unimproved (control) watercourses and individual respondents with respect to farm size or all sampled watercourses.

The Planning Division of WAPDA (1981) recently completed collection and tabulation of pre-watercourse improvement data on 45 watercourses being studied in an on-going evaluation throughout Pakistan. Four-fifths of these sample watercourses are currently being improved, and it will be interesting to see their comparative data and results after post improvement data collection and analyses.

All of the above studies, however, suffer from a common lack of adequate controls for estimations of the impact of watercourse improvement on productivity. Without the types of controls envisioned in this research in both sampling and production function analysis, it would be difficult to isolate the independent effect of watercourse improvement on productivity from all other effects.

The sampling controls envisioned include pairing sample improved and control watercourses with similar soil conditions, climatic conditions, cropping zones, waterlogging and salinity conditions, canal command position, watercourse commanded area, main watercourse length, number of farms and farmers, and canal outlet discharges. Other controls for the presence of tubewells, type of warabundi, etc. can be made through the production function analytic tool.

Discussion of these types of controls to ascertain the isolated effects of different institutions and technologies on productivity is the subject of the next chapter.

CHAPTER III

SAMPLING PROCEDURE AND DATA COLLECTION

The main objective of this research was a description of the irrigation system below the canal distributary outlets, in the joint-farmer-property watercourses. Focus was placed on describing the various elements of local farmer control of water supply, their interrelationships and their impacts on productivity. The sampling procedure was greatly influenced by the objective of evaluating the OFWM watercourse improvement project (another element of local flexibility). This evaluation effort was, in part, motivated by the considerable attention being focused by the Government of Pakistan, USAID, the Ford Foundation (the major funder of this research) and the World Bank on the economic impacts of and returns to the project.

Manpower, logistic and time constraints dictated that the sample be relatively small, yet large enough to permit comparisons of the strengths of relationships (and interrelationships) between local methods of control and productivity through production function and other statistical analyses. This, coupled with the intent of OFWM project evaluation, resulted in a sample of ten randomly selected improved watercourses and ten "paired" unimproved or control watercourses in the Faisalabad area. A sample of 130 individual farms was selected on these watercourses, stratified with respect to relative watercourse command position and farm size.

Use of the production function as a statistical tool

The selection of unimproved watercourses based on a paired sampling technique, as described in detail below, was an attempt to control for major watercourse characteristics, including length, canal outlet discharge, number of branches, number of farms and farmers, presence of tubewells, etc. The selection of individual farms, although stratified according to watercourse command position and farm size, was also based on paired sampling techniques (see below). Farmers were expected to differ in their use of inputs, which may account for part of the production changes attributed to watercourse improvement. It was also hoped that the research would unearth many unanticipated variations with respect to tubewell water use, trading of canal water, types of warabundi distribution systems, and even categories of improved watercourses.

Use of the production function analytic technique was, therefore, contemplated as a means of statistically controlling for these variations. Production function estimation using multiple regression techniques would enable the isolation of the effects of different control enhancing activities and selected inputs (X) on a dependent variable, gross value of production (Y), of the general form (see Heady and Dillon, 1961): $Y = f(X_1, \ldots, X_n)$. Detailed discussion of the production functions actually specified and estimated, their properties and interpretations, are presented in the analytic Chapters V and VI.

Sampling Procedure and Data Collection

Data collection took place on ten improved and ten unimproved or control watercourses. These watercourses were all similar in terms of a lack of general waterlogging and salinity, climatic and crop production zone, soil type, proximity to a large city and organized agricultural markets, relative canal command position and existence of pakka warabundi on main watercourse channels. All sample watercourses had silt loam soils, were in the middle of the Lower Chenab Canal command and were within a 12-mile radius of Faisalabad. Map 1, on the following page, shows the area of Pakistan and Faisalabad District where the field survey was conducted. Map 2, below, shows the location of branch canals and distributaries off of which sampled watercourses are located.[5]

Questionnaires and flow measurements

A combination of two types of questionnaires plus actual flume measurements of water flow at various positions on the main watercourses was conceived to collect watercourse level data. The watercourse level questionnaire (a copy of which appears in Appendix B) consists of two parts: (1) an interview of one or more "key informants"; and (2) a type of standardized scoring of the quality of cleaning and maintenance of each watercourse. The key informants were typically informal watercourse committee members on improved

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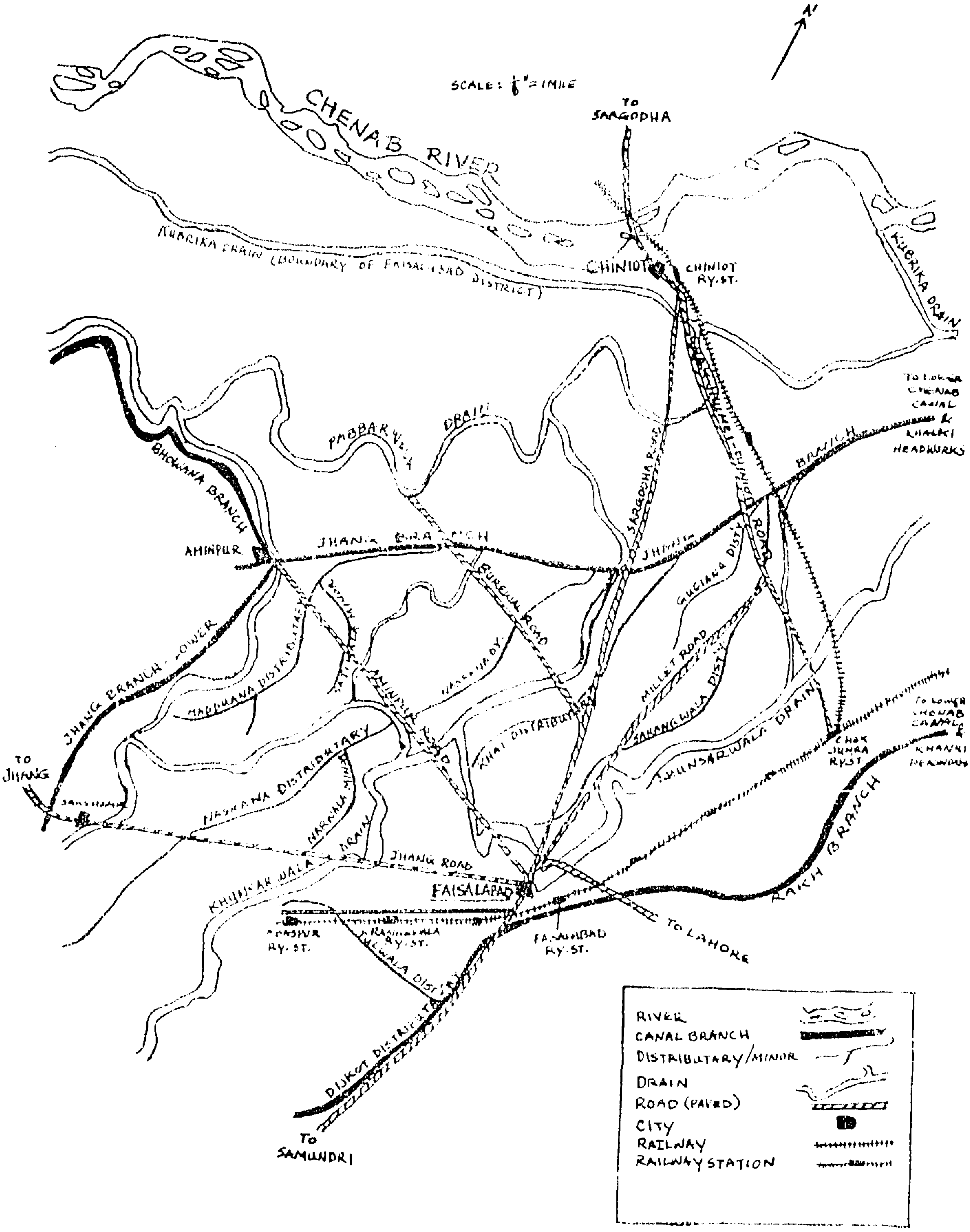
[5] This map is an amended version of the Irrigation Department's "Index Plan" for Faisalabad Irrigation Division.

Map 1. PAKISTAN – provinces, some major cities, neighboring countries, Faisalabad District (where the field survey was conducted) and major rivers.



Map 2. Branch Canals and Distributaries in the Faisalabad Area off of Which Sampled Watercourses are Located.

watercourses,[6] and relatively influential farmers on control watercourses, familiar with watercourse-related affairs. Questions asked of key informants relate to warabundi distribution, tubewell water sales, canal water trading and watercourse level cooperation. The scoring system is a revised version of that suggested by Mirza and Merrey (1979), expanded to encompass all types of watercourses.

The scoring system is based on actually traversing each sample main watercourse from canal outlet to the tail, assigning penalty points according to different categories affecting watercourse cleaning, maintenance and quality. Unfortunately, there were numerous problems encountered in assigning relative weights to these different categories. Consequently, follow-up water flow measurements were taken on each watercourse in cooperation with Lahore and Faisalabad OFWM personnel, who provided manpower, flumes and jeeps to assist the author, his two field assistants and his brother-in-law in this effort.[7] These measurements enabled accurate estimation of both conveyance losses (and indirectly, watercourse quality), and water flows received by individual sampled farmers.

The second type of questionnaire was designed to collect individual sample farmer data. The individual farmer questionnaire (a copy of which also appears in Appendix B) contains questions relating to

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[6] A watercourse committee or water user association is usually set up as part of OFWM watercourse improvement, primarily to collect money from farmers for associated masonry work.

[7] Canal water flows were estimated using cut-throat flumes (Skogerboe, et al., 1973), and the "trapezoidal" technique was used for estimating tubewell discharges (Trout and Early, 1976). Modifications in the proper use of flumes in the Punjab context were also exercised, according to Mohsin, et al. (1976) and (1979), Niazi and Ahmad (1976) and Ahmad and Early (1976).

farm production and input use, including farm size together with data relating to water use practices, such as canal water trading, tubewell water use (including sales or purchases), and type of warabundi practices on internal watercourses.

Since most cultivators speak only Punjabi the interviews were typically carried out by the field assistants in that language, although the questionnaires were filled out in English. The author was present during the great majority of interviews, except when touring the sample watercourses and subjectively scoring them. Each completed questionnaire was examined by the author immediately after the interview to ensure accuracy and clarity. The author would occasionally fill out watercourse level questionnaires with the help of key informants, when interviews could be carried out in Urdu. The author also supervised all flume water measurements.

The selection of sample watercourses

As indicated above, an equal number (ten) of improved and unimproved watercourses were selected, with many factors controlled for on all watercourses. Since all these factors affect productivity, control over them enables direct comparisons between the technological and institutional aspects which comprise the focus of this research.

Variations in watercourses were anticipated with regard to presence of private tubewells, (main) watercourse length, number of major watercourse branches, total watercourse command area, number of farms, and authorized canal outlet discharges.

Sample watercourses did, in fact, exhibit variation in these aspects; but differences were held to a minimum by a technique of pairing each sample improved watercourse, with an unimproved or control watercourse similar in each of the above respects.

The selection of individual sample farms

The design used for selecting individual sample farms and farmers to be interviewed was based on a stratified (non-random) sampling technique, in order to obtain a representative view of the total watercourse command. The design was to select two sample farms from the head one-third of the watercourse command, including the farm receiving the first scheduled warabundi turn (the first irrigator); two from the middle one-third; two from the tail, including the farm receiving the last scheduled warabundi turn (the last irrigator); and all tubewell owners.

The sample was also to be drawn so that it was representative of relative farm size categories. That is, whenever a farmer operating five acres or less (five acres is the approximate mean farm size in the Faisalabad area) was interviewed another farmer was to be interviewed in that same relative watercourse position operating more than five acres.

Unanticipated Factors

Several unanticipated factors emerged which affected the selection of sample watercourses. First, it was observed during pre-testing the questionnaires that watercourses had been improved as early as 1977 (the time of project inception), in the area around Faisalabad where OFWM watercourse improvements had been unusually active. Therefore, sampling of watercourses improved during different years (i.e., from 1977 to 1980) was carried out in order to determine whether benefit patterns were related to the year of improvement.

A second unanticipated aspect which emerged during pre-testing was that the great majority of watercourses, not only in the Faisalabad area, but in other areas of Punjab as well, have a pakka warabundi distribution system on the main watercourse. In fact, kachha warabundi was found to have survived only on very small watercourse commands (i.e., less than 150 acres) typified by a very small number of irrigators and irrigated farms (i.e., less than 20).

Discussions with several Irrigation Department, OFWM and WAPDA officials tended to confirm these observations. As noted above, available publications are also supportive of these tendencies (Lowdermilk, et al., 1978, and Mirza, et al., 1975).

Consequently, all sample main watercourses were ones practicing pakka warabundi. Variation did exist, however, with respect to the type of warabundi practiced on internal watercourses.

Other unanticipated aspects emerged during actual surveying work. Improved and control watercourses were paired with respect to "authorized" canal outlet discharge, but during the course of taking water flow measurements it was realized that actual discharges are not consistent with authorized ones.

Also, watercourses selected on the criteria of mere presence of a tubewell, did not, unfortunately, necessarily exhibit similarities with regard to ownership pattern or source of power. It was later observed that these facets of private tubewells significantly impacted use of tubewell water.

Of course, all these efforts to control for seemingly extraneous factors were eventually partially controlled for through production function analysis. It can, nevertheless, be hypothesized that these efforts at control strengthened any production function estimates.

Statistical Description of the Sample

Table III-1, below, shows some of the characteristics of the sampled watercourses.

Three of the sampled improved watercourses have a cooperatively owned (electric) tubewell serving all the farmers on these watercourses, but no sampled control watercourses have this ownership arrangement. In fact, none could be found in the Faisalabad area. Consideration was given to eliminating any improved watercourses with a cooperatively owned tubewell from the sample, but because these particular tubewell ownership patterns presented another potential means to gain added flexibility over water supplies, it was decided to retain them in the sample.

The sampled improved watercourses also show a marked tendency to either have electric-powered tubewells, or no tubewell at all; whereas the sampled control watercourses tend to either have diesel-powered tubewells, or no tubewell at all. This sampling bias is unfortunate, but is thought to be random, and controlling for the type of tubewell power source would have meant sacrificing some or all of the other controls.

Major statistics with respect to the 20 sampled watercourses are presented in Table III-2. This table reveals several interesting features. The average length of lined sections on sampled improved

Table III-1. Summary Characteristics and Categories of Sampled Watercourses (total numbers, means and standard deviations).

	OFWM improved watercourses	Unimproved or control watercourses
Total number	10	10
No. improved in 1977	3	--
No. improved in 1978	3	-
No. improved in 1979	3	-
No. improved in 1980	1	-
Total no. of watercourses with private tubewells	7	7
No. with single family owned tubewells(s)	3	4
No. with joint family owned tubewell	1	3
No. with cooperatively owned tubewell	3	0
No. with one tubewell	5	6
No. with two or more tubewells	2	1
No. with electric-powered tubewell(s)	6	2
No. with diesel-powered tubewell(s)	1	5

	Mean	Std. Dev.	Mean	Std. Dev.
Average main watercourse length with branches (feet)	15,730	4,093	17,193	6,121
Average no. of branches off main watercourse channel	3.6	1.7	3.5	1.4
Average watercourse commanded area (acres)	373.0	71.6	381.35	64.6
Average no. of farms	78.9	25.5	91.7	24.2
Average size of farm (acres)	5.2	1.8	4.3	0.7
Average authorized canal outlet discharge (cusecs or c.f.s.)	1.11	0.23	1.14	0.23
Average authorized canal outlet discharge per commanded acre $(\frac{c.f.s.}{acre})$	.003	0.0002	.003	0.0002

Table III-2. Major Characteristics of Each Sampled Watercourse.

(1) Water-course or moga s. no.	(2) Name of adjoining canal distributary	(3) Total CCA (acres)	(4) Total no. of farms	(5) Average size of farm (5÷6) (acres)	(6) No. of sampled farms	(7) Total main water-course length (feet)	(8) No. of major branches	(9) Month and year water course improved (if applicable	(10) Length of lined section (feet)	(11) % of lined section to total length ($\frac{12}{9}$x100)	(12) No. of tube-well present (sampled)	(13) Type of ownership of tube-well a/	(14) Type of tubewell power (E=Electrified D=Diesel)	(15) Estimated discharge of each tubewell (c.f.s.) b/	(16) Authorized canal outlet discharge (Irrig. Dept.) (c.f.s.)	(17) Actual canal outlet discharge (c.f.s.) c/	(18) % diff. between authorized & measured discharges ($\frac{19-18}{18}$x100)
1	Nasrana	415	104	4.0	7	14,300	2	Sept. 77	440	3.1	2	S,S	E,E	.79 .72	1.22	1.45	19
2	Nasrana	450	114	4.9	6	20,900	6	Aug. 78	2,640	12.6	0	-	-	-	1.36	2.10	54
3	Nasrana	362.5	73	5.0	7	9,900	2	Dec. 77	660	6.7	1	J	E	1.57	1.09	1.10	1
4	Tulwala	245	58	4.2	6	9,900	1	Aug. 78	220	2.2	0	-	-	-	.65	.85	31
5	Tulwala	350	93	4.2	6	13,750	4	Aug. 78	1,210	8.8	0	-	-	-	.99	2.20	122
6	Khai	275	28	4.8	6	15,400	3	Dec. 77	1,540	10.0	1	C	E	1.1	.93	1.13	21.5
7	[illegible]	465	79	5.9	6	22,000	6	April 80	1,980	9.0	1	C	E	1.25	1.40	1.73	24
8	Khai	375	61	6.1	6	17,050	3	July 79	1,100	6.5	1	C	E	1.2	1.12	1.40	25
9	Nasrana	430	87	4.9	7	18,700	4	Feb. 79	1,595	8.5	1	S	D	1.2	1.34	2.40	79
10	Nasrana	362.5	102	3.6	8	15,400	5	July 79	1,320	8.6	2++	S,S	E,E	1.45 1.48	1.03	.85	-17
Mean for All Sampled Improved Watercourses		373.0	78.9	4.7	Total = 65	15,730	3.6	30% 77 30% 78 30% 79 10% 80	1,270.5	8.1	0.9	56% S 11% J 33% C	89% E 11% D	1.20	1.11	1.52	37
11	Nasrana	500	130	3.8	7	30,580	3	-	-	-	1	S	D	1.2	1.56	2.60	67
12	Nasrana	475	107	4.4	6	19,140	6	-	-	-	0	-	-	-	1.50	[illegible]	63
13	Nasrana	387.5	117	3.3	7+	19,140	5	-	-	-	1	J	D	1.2	1.13	1.20	6
14	Tulwala	284	54	5.4	6	7,700	2	-	-	-	0	-	-	-	.79	.70	-11
15	Dijkot	375	84	4.5	6	18,040	2	-	-	-	0	-	-	-	1.00	1.30	30
16	Khai	354	70	5.1	6	20,900	4	-	-	-	2	S,S	E,D	1.1 .8	1.05	1.84	75
17	Khai	392	78	5.0	7	13,200	2	-	-	-	1	S	E	1.2	1.11	1.40	26
18	Madduana	325	73	4.5	7	13,200	3	-	-	-	1	S	D	1.2	1.05	1.65	57
19	Sarangwala	371	111	3.3	7	16,500	5	-	-	-	1	J	D	.9	1.16	1.00	-14
20	Sarangwala	350	94	3.7	6	13,530	3	-	-	-	1	J	D	1.2	1.07	1.35	26
Mean Averages for All Sampled Unimproved or Control Watercourses		381.35	91.7	4.2	Total = 65	17,193	3.5	-	-	-	.8	62.5% S 37.5% J	25% E 75% D	1.10	1.14	1.55	36
Mean Averages for All 20 Sampled Watercourses		377.2	85.3	4.4	Total = 130	16,461.5	3.55	-	-	-	.85	59% S 24% J 19% C	59% E 41% D	1.15	1.125	1.535	36

a/ S = Single family; J = Joint family; C = Cooperative.
b/ Measured using 8" x 3' cut-throat flumes.
c/ Measured using the Purdue Coordinate Method.
+One respondent owned a tubewell, but no land, on this watercourse.
++There are actually four single-owned tubewells on this watercourse, but only two sell tubewell water and these were sampled.

watercourses is about 1,270.5 feet or almost a quarter of a mile. Approximately 8 percent of the total main watercourse length is lined on sampled OFWM improved watercourses, on average, with a range between 2 to 13 percent.

The overall average discharge from seventeen measured tubewells was 1.15 c.f.s., ranging from an average discharge from ten electric-powered tubewells of 1.19 c.f.s., to an average discharge from seven diesel-powered tubewells of 1.10 c.f.s. The significance of having an electric-powered tubewell, as opposed to a diesel-powered tubewell, on a watercourse is not so much a function of higher pumping capacity but rather of cheaper operating (energy) costs and a cheaper market price, as discussed in more detail below.

Systematic measurements of canal outlet discharges were made using 8 inch (throat width) by 3 feet (total length) cut-throat flumes, based on the published methods mentioned above and also on consultation with certain WAPDA and OFWM engineering staff. The measurements, taken in September 1981, are presented in column 17 of Table III-2, and indicate an overall mean discharge of 1.535 c.f.s., ranging between .70 c.f.s. and 2.60 c.f.s. A comparison of authorized discharges and "actual," measured discharges reveals that actual discharges are consistently higher than authorized discharges, of the order of 36 percent difference overall (see column 18). On only three sampled watercourses was the authorized discharge greater than the actual discharge.

Other sample watercourse and farm differences

There are, of course, many other differences between villages, watercourses and farmer-irrigators that are difficult to control. These differences such as leadership, education, caste, origin, degree of cooperation (i.e., number of cooperative projects and/or disputes in the village in recent memory), number of active organizations, and number of institutional services -- can prepare one village for economic progress but not another. Some of the changes observed on the improved watercourses may be due to uncontrolled variables which are not duplicated on other watercourses and in other villages. However, the education level of sampled farmers was almost identical: a mean of 4.00 years of schooling on improved watercourses and 3.97 years on control watercourses, with no significant difference demonstrated at the 5 percent level using the t-test.

Tables III-3 and III-4, below, show the caste and origin distinctions between the two types of watercourses, with relative frequencies, computed chi-square test values and corresponding significance levels. Table III-3 demonstrates that there are significant differences (at the 2.5 percent level) between the two types of watercourses with respect to caste. In particular, control watercourses appear to have considerably more Jats, and fewer Rajputs, than imrroved watercourses. However, both types of watercourses are dominated by Jats, and the frequency of castes other than Jats and Rajputs is remarkably similar between the two types.

Table III-4 shows that there are no significant differences between the two types of watercourses and origin status. Both types of

Table III-3. Type of Watercourse and Caste Differences.

Number of major caste	Improved watercourse	Unimproved watercourse	Row total	Relative row frequency
Jat	28	41	69	.53
Rajput	20	6	26	.20
Arain	11	11	22	.17
All other*	6	7	13	.10
Column Total	65	65	130	
Relative Column Frequency	.5	.5		

*All other includes Dogar, Gujar, Gondal, Sheikh, Christian and Nai (Barber).

x^2 = 10.07, d.f. = 3, significance level = 2.5%

Table III-4. Type of Watercourse and Origin Differences.

Origin category	Improved watercourse	Unimproved watercourse	Row total	Relative row frequency
Local*	0	2	2	.015
Settler*	20	13	33	.254
Refugee*	45	50	95	.731
Column Total	65	65	130	
Relative Column Frequency	.5	.5		

*Local means the original inhabitants of canal irrigated areas; settler means the persons who settled the canal colonies in the late 1800's and early to mid-1900's; refugee means the persons who emigrated from present day India to present-day Pakistan at the time of independence from the British in 1947.

3.81, d.f. = 2, significance level = 25%

watercourses are apparently dominated by refugees, with a lower frequency of settlers and practically no locals.

The results from Tables III-3 and III-4 are generally consistent with the observations of Mirza and Merrey (1979), who showed that watercourse improvement tended to occur on refugee and settler dominated watercourses. Their finding that watercourse improvement also tended to occur on watercourses dominated by one particular caste does not appear to be true of this particular sample. However, this hypothesis cannot be adequately tested because of the non-random nature of the sampling of farms.

With regard to overall watercourse-level relationships, there is no significant difference between type of watercourse and number of water-related disputes on the watercourse, as shown by the t-test, but there are significant differences between number of collective projects, number of active organizations and number of institutional services in the village.[8]

The types of water-related disputes include water theft (and related murder cases), refusal to turn canal water over to downstream irrigators (due to disagreements over what reaches were included in the sanctioned main watercourse), last farmer status at the end of main channels and branches and use of illegal (unsanctioned) nakkas off the main watercourse.

The type of cooperative projects include watercourse improvement, lining of village drains, mosque committees, collective tubewells,

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[8] The respective 95 percent confidence intervals (student's distribution) for these four factors are .3±.385, 1.8±.58, 2.7±.58 and 2±1.41.

school projects, village road improvements, cash input procurement societies, and village libraries. Active organizations in the villages include mosque, zakat (obligatory payment by all Muslims of approximately 2.5 percent of one's net worth to poor and needy persons) and islahi (amendment) committees, panchayats, cooperative (bank and cash input) societies, Union Council offices and water user associations (on OFWM improved watercourses only).

The types of institutional services present include major paved roads, village electrification, railway stations, bus stops, post offices, government fertilizer agencies, Provincial Agriculture Department field assistants, local grain or livestock markets, boys' and girls' schools, government medical and veterinary dispensaries and bank branches.

The observed tendencies are for more collective projects, active organizations and institutional services to be present on improved watercourses. This is, no doubt, in part due to the fact that OFWM officials tend to choose the watercourses to be improved which are easily accessible by road and nearby their local OFWM headquarters (team offices), where other institutional services tend to congregate. It is also partly due to the tendency for watercourse improvement to take place with the cooperation of the majority of irrigators on watercourses (and in villages) where previous cooperation in other projects and organizations has already occurred to some degree (i.e., having an average of two or more collective projects).

We continue this discussion of the sample in the following chapter, emphasizing the physical and institutional background of local irrigation systems in sampled areas. This extensive description of the overall system, agronomic environment, watercourses, tubewells, warabundi, trading and process of watercourse improvement is necessitated by the general lack of adequate detailed information in the literature.

CHAPTER IV

DESCRIPTION OF PHYSICAL AND INSTITUTIONAL SETTING

Much of this chapter presents descriptive empirical findings of the study regarding tubewell use, water trading and kachha internal warabundi. In order to make these descriptions intelligible, it is necessary to first describe the physical irrigation system and explain the Pakistani warabundi system. As noted in Chapter II, this system and the similar warababundi system of North India have been partially described elsewhere in the literature. However, because there is no succinct description of the Pakistani system and because so much is misunderstood, this chapter includes a detailed description of this system.

The Macro Environment of Irrigation

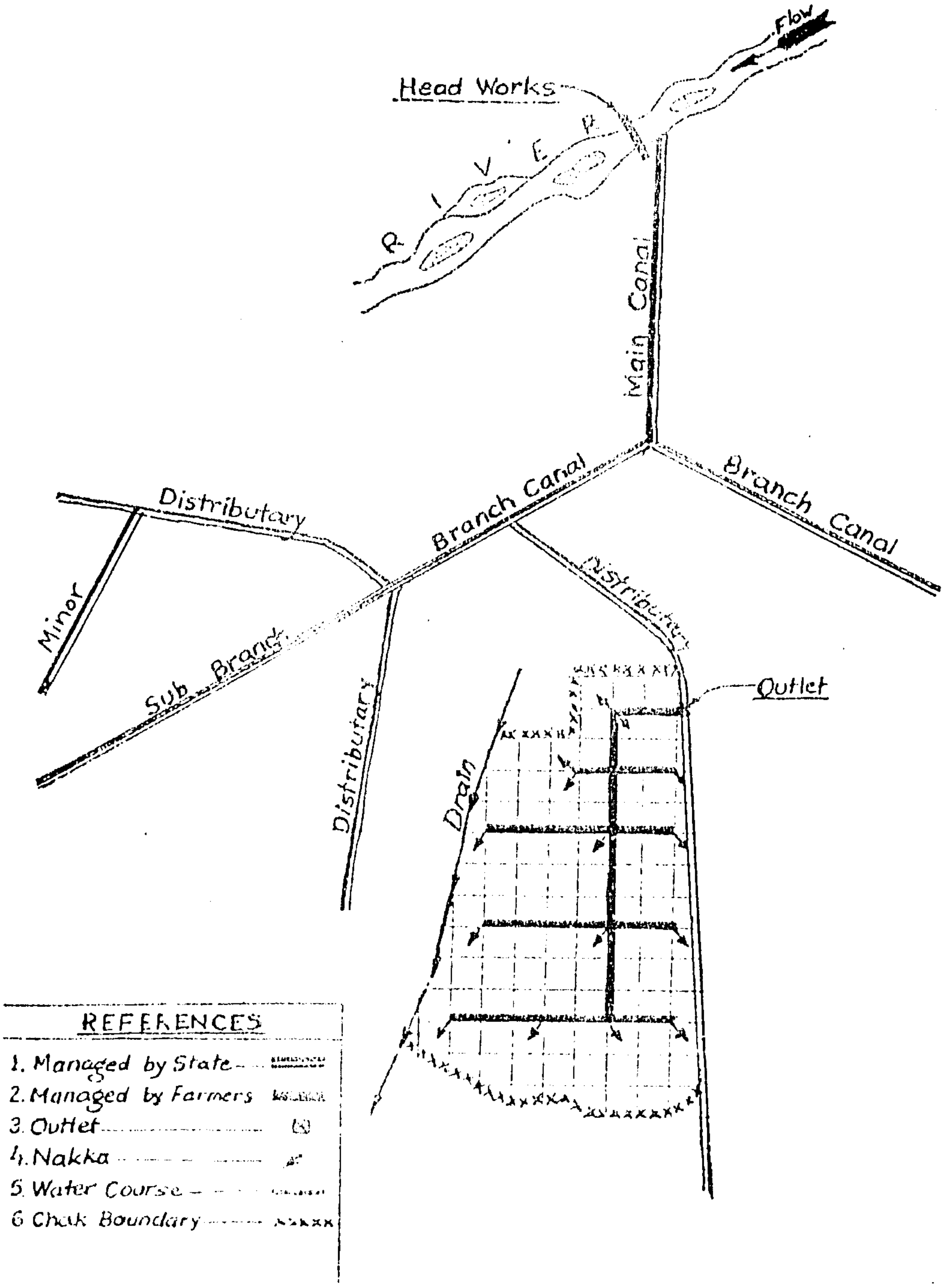
We begin with a broad look at the canal irrigation system, the system of watercourses and grouping of watercourses into administrative units called "chaks."

The canal irrigation system

The flow of water originates mainly in the Himalayan mountain watersheds, supplemented by the smaller plains river system. From the major rivers, it is diverted into main and branch canals, into distributaries and minors, then through a fixed outlet (called a "moga") into the main or primary watercourses to farmer's internal or secondary watercourses and individual field parcels through smaller outlets (nakkas).

Several key references describe the development and major characteristics of the canal irrigation system in the Indus basin, including WAPDA (1979), Lieftinck, et al. (1968), Gibb, et al. (1966) and Lowdermilk, et al. (1978). These sources provide details of the current system which irrigates an area of some 35 million acres through several link canals (taking water from western rivers to supplement eastern river flows), 43 major canals using river water diverted by 16 barrages to tens of thousands of watercourses.

After Malhotra (1980), Map 3 shows a typical surface irrigation distribution system. Four or more conveyance types, according to size, can be identified. These include main canals, branch canals, distributaries and watercourses. River flows are diverted by a structure of headworks into a major (main) canal. Weir and gate structures at junction points divert water into branch canals and sub-branches and into distributaries and minors. Canal outlets permit continuous flows of water from distributaries and minors at regular intervals into watercourses. Canal outlets are fixed, brick and cement structures with small apertures which are constructed such that each watercourse receives a continuous flow without the necessity of periodic regulation by the Irrigation Department. The main watercourses as well as the smaller outlets off the main watercourse are determined and sanctioned (i.e., made legal) by the Irrigation Department, although the operation



Map 3. Typical Irrigation Water Distribution System in Pakistan (adapted from Malhotra, 1980).

and maintenance of the system below the canal outlet is left to the farmers.[9]

Chaks and watercourses

The final links in the canal irrigation system for delivery of water to the crops are the series of main and internal watercourses. In each canal command the irrigated land is divided into administrative units called "chaks." A chak has no pre-ordained size, but usually corresponds to the area historically included in a village or in two or more sub-villages. The typical main watercourse command area in the areas surveyed for this study is about 400 acres.

It is the responsibility of the Irrigation Department to deliver canal water to all land included in the commanded or irrigated area of the chak, and the number and lengths of main, sanctioned watercourses vary in order to meet this objective. To assist in this task, the land in a chak is divided into squares or partial-squares, where a typical full-square in the Faisalabad area is 25 acres, and are assigned numbers beginning with the number one. Each square or partial square is then assigned a sanctioned (official) smaller nakka outlet off the main watercourse from which to receive canal water.

The canal outlets, main watercourses and major nakkas are specified and sanctioned in every case by the Irrigation Department with the

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[9] There are special cases when Irrigation Department officials intervene in operations below the canal outlet. These include the sanctioning of main watercourses, with branches and major nakkas off the main channels, the sanctioning of pakka warabundi schedules and the settlement of water related disputes. See the Canal and Drainage Act of 1873 (Nasir, 1981) for details, official responsibilities and jurisdiction.

objectives of delivering water to each and every square in the command area with the minimum possible overall length and corresponding seepage and transient losses, subject to topographical elevation constraints.

Given the slope of the land and the pre-determined division of the chak's command area into a grid pattern of 25 acre squares, Irrigation Department engineers must design a system of main watercourses and limited number of nakkas to deliver water to each square. Although often ignored, the irrigation engineer's task includes coordinating these plans for the respective chaks with the overall delivery capacity of the entire distributary or minor, guaranteeing that each chak, and further each main watercourse, is accorded its appropriate share of the total flow available in the distributary or minor in relation to its command area, discounting losses in the canals. An appropriate distribution model must, of course, take into account these losses.

In theory then, each outlet on the distributary is accorded a discharge directly proportionate to the commanded area serviced by its main watercourse. No compensation is currently made to downstream outlets for canal seepage losses. Originally, the sizes of watercourse commands were established on the basis of overall river-flow rates, designed cropping intensities and assumed cropping patterns and irrigation requirements. Since cropping intensities in the original design were very low in comparison to the current objectives of increased intensification with higher yields per acre and shift to more higher-valued (and higher water using) crops, the watercourse systems as they now exist constrain both capacity and flexibility of water deliveries.

Each square typically has one sanctioned nakka, but as many as two or three nakkas may be sanctioned in a single square if there are considerable slope variations and certain fields in a square cannot effectively get canal water from one nakka alone without incurring considerable dead storage losses. The authorized nakkas are indicated on the Chak Plans,[10] and the users of any other nakka found on the main watercourse are punishable by a fine of Rs. 200 (maximum) per offense and/or imprisonment not exceeding three months (Nasir, 1981). Reducing to a required minimum the number of earthen nakkas on the main watercourse helps to reduce seepage losses.

At nakka locations, water is diverted into the various branches of the internal watercourses by constructing earth dams in the main watercourse just adjacent to or slightly downstream of the nakka opening, and to individual fields by cutting into the main watercourse bank, and later restoring it. These continual cuts into the banks and incomplete restorations contribute to seepage losses throughout the length of the main watercourse.

One curious aspect of the system is that there is no general provision for runoff into the system of open drains from either the distributaries or watercourses, presumably because flows into distributaries can be cut-off during periods of heavy rain and flooding, and because surplus supplies are assumed to not exist during other

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[10] Chak Plans are detailed maps of the area included in the chak command with location of outlets, main watercourses and branches, sanctioned nakka outlets off the main watercourse, village locations, open drains, roads and unirrigated lands. The canal outlets ("mogas") are specified with a title and number, R.D.# (reduced distance -- distance in meters from the junction of the distributary with the branch canal), and a specification of whether the outlet is on the right (R) or left (L) hand side of the distributary in relation to the direction of canal flow. Copies of Irrigation Department Chak Plans are included in Appendix A, and show details of sample watercourses surveyed in this research.

periods. Nevertheless, there are occasions when farmers do not desire the full supply of canal water being received: notably in times of heavy monsoon rains; in the later growth stages of certain crops just prior to harvesting when heavy irrigations may actually decrease yields; and where waterlogging (condition of a high groundwater table) may be a problem.

To help cope with all these situations of real or potential surplus conditions, the main watercourse could in many cases be extended to allow watercourse run-off into an adjoining drain.

The Agronomic Environment

References to the physical soil-crop-water relationships are a recurring theme throughout this report. It has been remarked that this study does not examine these relationships through estimation of explicit water response functions. However, an overview of the crops grown in areas surveyed in relation to the two major seasons and predictable seasonal peak water demand periods will facilitate understanding farmer motivations in tubewell water selling and canal water trading activities.

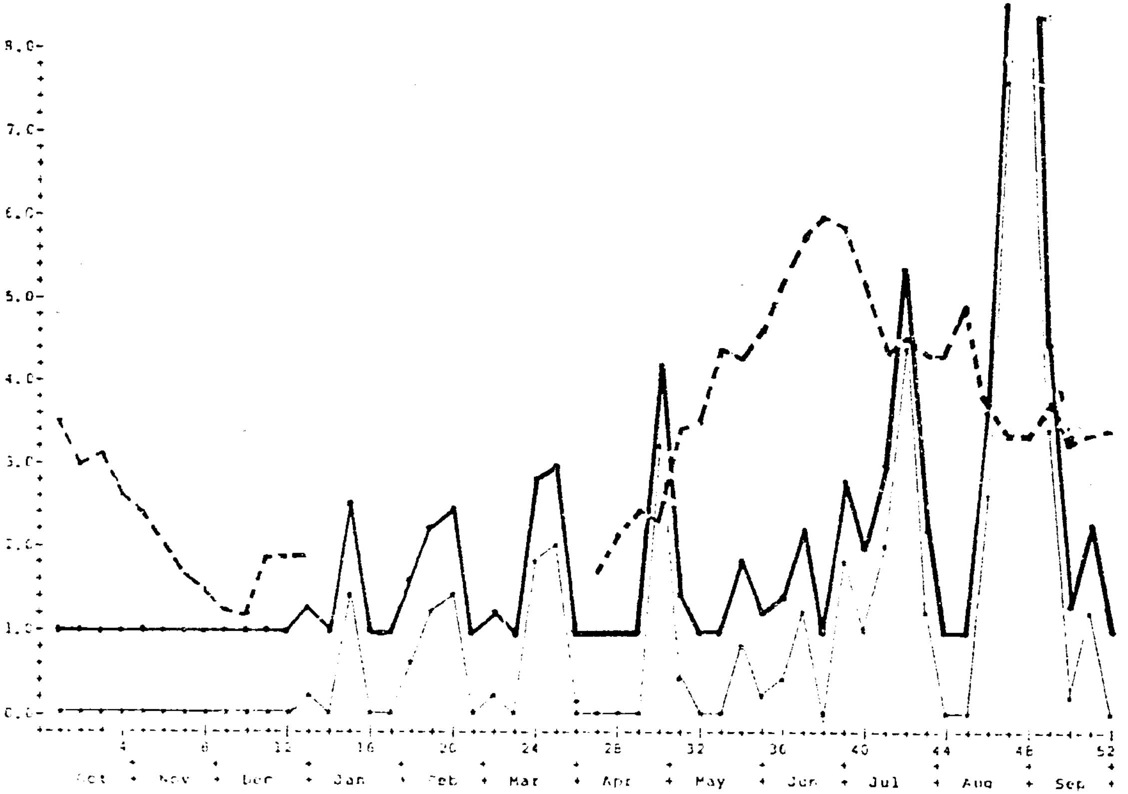
The major summer crops grown in the surveyed Faisalabad area are maize and sorghum fodders, maize grain, and relatively lesser amounts of rice, cotton, vegetables, fruits and tobacco. The major winter crops are wheat, fodder (primarily berseem), with some vegetables and fruits. Sugarcane is the major cash crop and has a year-long maturity period (unless cut prematurely for fodder).

The major periods of high seasonal demand for irrigation water are: (1) March and April, when heavy presowing irrigations are given in anticipation of major sugarcane crops; (2) May and June, when heavy presowing irrigations are applied in expectation of major fodder crops, and when temperatures are at their highest in the year and stresses on sugarcane and fodder crops in early growth stages are also the highest; (3) August, when some heavy presowing irrigations are given to maize grain crops, prior to the onset of monsoon rains in August and September; and (4) October, November and December, when heavy presowing irrigations are applied to important wheat and fodder crops in the winter season, and when anticipation of annual canal closures (typically for four to six weeks in December and January) encourage heavier than usual irrigations.

Isolated and infrequent frosts in the winter season (typically in January and February) may also stimulate water demand in attempts to warm soil temperatures and preserve plant growths. Periodic sudden rises in temperature and stress conditions throughout the year also bring about unpredictable transient peak demand.

A diagram of weekly rainfall for a Punjab experimental station in 1975, reproduced below from Reuss (1980, p. 43), demonstrates periods when water supplies are typically low. Canal water supplies on a typical watercourse are assumed by Reuss to be constant at about one cm per week. The figure on the following page shows the rainfall plus the canal water supplies assumed by Reuss, plus weekly evapotranspiration for nine-month sugarcane crop also present in Reuss. Notice the divergence of evapotranspiration and water supplies during the months of April, May-June, August, and October-December.

The important difference is the vertical distance between the evapotranspiration and the net water supply. Note that this distance



— = Weekly rainfall (cm) for the Sargodha Station in 1975.

▬ = Weekly rainfall (cm) + canal water supplies of 1 cm per week in 1975.

-- = Weekly evapotranspiration (cm) for nine-month sugarcane crop in 1975.
(Assuming planting date of April 1 and harvest date of December 25.)

Figure IV-1. Weekly Rainfall Canal Water Supplies and Evapotranspiration (cm) for Sugarcane in Sargodha, 1975.

is subject to considerable weekly variation which can be accounted for by alternate periods of rainfall and intense heat. The general shape of this difference will be the same from year to year, but the profile of weekly spikes will vary. It is the unpredictability of this weekly profile which motivates the demand for flexible water supplies.

Irrigating with Tubewell Water

The typical method of irrigating with tubewell water is to simultaneously use (mix) this water with canal water; that is, for individual irrigators to arrange for the pumping of tubewell water into the watercourse during one's warabundi turn at the full discharge of canal water being received through the outlet. The reasons for doing this are likely twofold: one, to minimize seepage and transient losses; and two, because of the (pakka) warabundi scheduling.

Losses can be minimized by using tubewell water simultaneously with canal water because once the dry perimeter of the watercourse is wetted in the normal course of warabundi, adding tubewell water to a wetted perimeter will maximize the amount of tubewell water reaching the field. Of course, if an irrigator is in dire need of water on any particular day (due to stress conditions) he may disregard this factor, and try to bring tubewell water to his crops regardless of whether it is his turn at canal water on that day or not. In fact, the major reason for using tubewell and canal water simultaneously is undoubtedly the limitation on tubewell water use imposed by warabundi.

If, for example, a tubewell is located at the head of a watercourse, downstream users and/or purchases of tubewell water can only use this water during their own turn, when they have uninterrupted right to the total discharge and flow in the watercourse, or when the main watercourse length between their nakka location and the tubewell location is unused or empty of water.

From the point of view of irrigators downstream of the tubewell, the main watercourse is empty only when upstream users (upstream from the tubewell location) are diverting all canal water flows through the outlets into their internal watercourses and fields. This period of upstream diversion may be very short if the acres irrigated upstream of the tubewell are very few. It can be longer the farther the tubewell is located down the watercourse. But if this is the case, then the number of potential users and purchasers of tubewell water will be fewer, since fields located upstream from a tubewell cannot use tubewell water, if canal water irrigation is also practiced, unless another set of watercourses is present solely or primarily for tubewell water conveyance.

To make this clear, we consider Map 4, below, of sampled watercourse No. 20. We see from the map of this watercourse that a tubewell is located in square No. 86, near the major paved road, roughly in the middle one-third of the watercourse command. This is a small diesel tubewell of estimated 1.2 cusec discharge, jointly owned by four cultivators with landholdings in square numbers 86 and 90 (among other fragmented holdings at head, middle and tail locations). This tubewell can irrigate lands in squares 86, 90, 85 and 91, by conveying the water through an internal watercourse (not drawn) to roughly point F, where it meets the main watercourse (the elevation of the tubewell is higher than at point F). Fields irrigated off the main watercourse upstream

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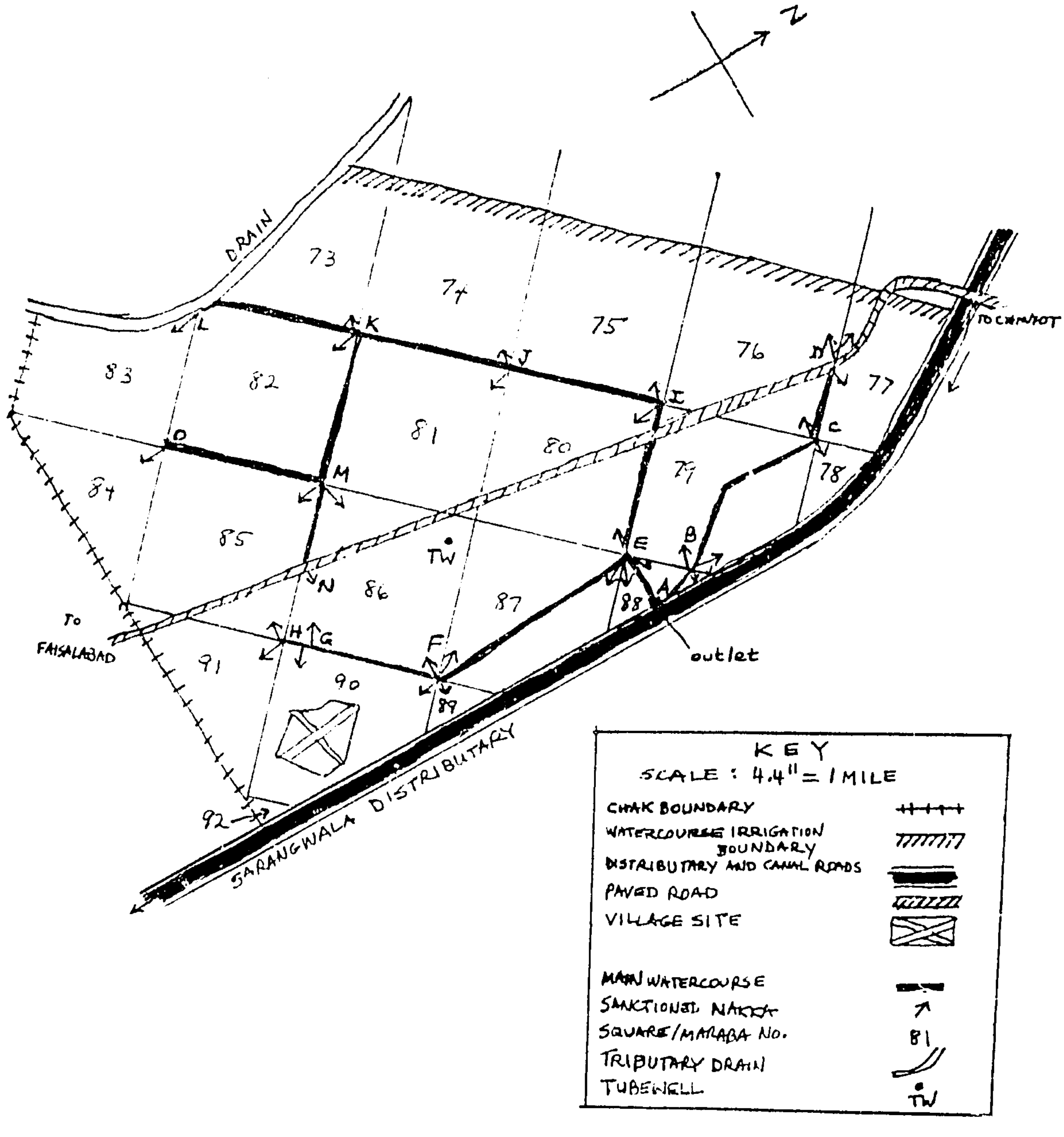

Map 4. Detailed Map of Sampled Watercourse No. 20.

of point F cannot effectively use this tubewell water because of higher slope conditions.

The tubewell could be used to irrigate lower elevation lands on the other side of the paved road (such as lands in square numbers 86, 85 and 84), but no internal watercourse was constructed to pass under the paved road for this purpose. The joint owners of this tubewell apparently feel that their returns are maximized by having the tubewell located on the tail of this branch where most of their lands are positioned. However, if sufficient demand for timely tubewell water exists on this watercourse, and if many other irrigators will pay the price demanded to cover all costs, then both social and individual returns might be increased by placing the tubewell at the head. Since this is a generally sweet water area this is a feasible alternative as well.

Nevertheless, the current situation dictates that only the lands in squares 86, 90, 85 and 91, on the same side of the road as the tubewell, can effectively utilize groundwater pumped up by this tubewell. Cultivators in square No. 86 as well as those downstream from point F, can use the tubewell water with canal water during their own turns, or alone without canal water mixing when the upstream sections of the main watercourse are empty. The collective turn for this area included in four squares, as seen below from the pakka warabundi schedule for this watercourse, includes turn numbers 8-15 and lasts a total of 28 hours and four minutes, not counting nikal time (see columns 2 and 5). Since the irrigators in square No. 86 on this branch must transport the water from point E (the junction of the branch and the main channel section) to point F to begin their turns, the watercourse branch above point F remains empty for a long period of 139 hours and 20 minutes.

Consequently, for all practical purposes, the irrigators on this particular branch can utilize tubewell water virtually any time.

However, if the tubewell was located at the head between points A and E, for example, few, if any, irrigators on the right-hand branch could use tubewell water, and all downstream users from point E could only use tubewell water during their respective turns when water is diverted upstream into the right-hand branch. Other considerations of tubewell water sales and use are discussed below in subsequent sections of this chapter.

The two basic types of warabundi

It will be recalled from Chapter I that there are two basic types of warabundi: "pakka" and "kachha."[11] The principal advantages of both types were also specified.

Kachha warabundi was most common in Punjab in the early days of the large-scale canal settlements in the late 1800's and early 1900's when the number of irrigators per canal and watercourse command were considerably fewer than the present, and time-keepers (often village headmen or religious leaders such as Muslim maulvis or Hindu priests) were employed and provided with clocks to dictate when a person's time to irrigate began and ended.

The time-keepers served an additional purpose of facilitating exchanges or trades in canal water, acting in a limited way as irrigation water market coordinators. With the spread of inexpensive wrist

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[11] Since no good English translations exist of the concepts "pakka" and "kachha" in the context of warabundi, these local terms will be retained throughout this dissertation.

watches and clocks throughout the population, the principal role of the time-keeper was largely gone, and time-keepers are seldom encountered today on watercourses in the Punjab. Apparently, his role in coordinating water exchanges was not appreciated highly enough in the majority of cases to warrant his continued employment, or the very presence of pakka warabundi could not allow him to function in this role.

An Example from Pakka Warabundi

Detailed descriptions of pakka warabundi are only found in the Canal and Drainage Act (as interpreted by Nasir, 1981, and more recently, by Malhotra, 1980). Since neither of these descriptions is entirely complete nor particularly succinct, another interpretation is presented here.

A typical pakka warabundi schedule is presented below. This schedule corresponds to Map 4, above, of sample watercourse No. 20. The watercourse map and warabundi schedule are copies obtained with the consent of the Faisalabad Division irrigation authorities, prior to translations from Urdu and minor revisions based upon field observation.

As seen from Map 4, this is an unimproved watercourse with a total irrigated area of 351 acres, and a total watercourse length of 13,530 feet or 2.56 miles. It consists of a main channel 6,160 feet long (from positions A to O, also including points E, I, J, K and M, on the map), two major branches (one connecting points A to D, and the other from E to H), and two very small branches (one from K to L, and the other from M to N).

Table IV-1. Sanctioned Pakka Warabundi of Sampled Watercourse No. 20, Faisalabad Division (sanctioned March 22, 1974).

(1)	(2)	(3)	(4)	(5)		(6)	(7)		(8)	(9)		(10)		(11)	(12)	(13)	(14)	(15)	(16)
														Location of Reach		Schedule A[b]		Schedule B[b]	
Sequential no. of turn	Total no. of irrigators included in this turn	Square/ no.	Total CCA on watercourse (acres)	Allotted time based on farm size		Length of upstream reach (ft.)	Time/ Addition: bharai or lead time		Length of watercourse emptied (ft.)	Time/ Deduction: nikal or emptying time		Net allotted time without nikal[a] (5+7-9)		Position where water is taken over (beginning of reach)	Position where water is turned over (end of reach)	Day and Time of Turn		Day and Time of Turn	
				H[c]	M		H	M		H	M	H	M			Start	End	Start	End
1	1	88	1.9	0	52	0			0			0	52	Outlet	A	M6:00AM	M6:52AM	M6:00PM	M6:52PM
2	4	79	24.5	11	30	220	0	05	0			11	35	A	B	M6:52AM	M6:27PM	M6:52PM	T6:27AM
3	4	78	3.2	1	30	1,320	0	30	0			2	00	B	C	M6:27PM	M8:27PM	T6:27AM	T6:27AM
4	10	76	26.0	12	30	880	0	20	0			12	50	C	D	M8:27PM	T9:17AM	T8:27AM	T9:17PM
5	4	77/76	14.4	6	48	0			2,860	0	39	6	09	D	D	T9:17AM	T3:26PM	T9:17PM	W3:26AM
6	3	88	1.2	0	32	440	0	10	0			0	42	A	E	T3:26PM	T4:08PM	W3:26AM	W4:08AM
7	5	87,88,89	14.33	6	45	660	0	15	0			7	00	E	E	T4:08PM	T11:08PM	W4:08AM	W11:08PM
8	6	89,86	10.3	4	50	1,540	0	35	0			5	25	E	F	T11:08PM	W4:33AM	W11:08PM	W4:33PM
9	3	86,87	11.4	5	20	220	0	05	275	0	03	5	22	F	F	W4:33AM	W9:55AM	W4:33PM	W9:55PM
10	3	90	13.5	6	23	0			0			6	23	F	F	W9:55AM	W4:18PM	W9:55PM	Th4:18AM
11	1	90	3.2	1	23	0			0			1	23	F	F	W4:18PM	W5:41PM	Th4:18AM	Th5.41AM
12	2	86	1.9	0	53	660	0	15	0			1	08	F	G	W5:41PM	W6:49PM	Th5:41AM	Th6:49AM
13	1	90	1.05	0	29	220	0	05	0			0	34	G	G	W6:49PM	W7:23PM	Th6:49AM	Th7:23AM
14	1	65	4.05	1	54	220	0	05	0			[illegible]	59	G	H	W7:23PM	W9:22PM	Th6:49AM	Th9:22AM
15	1	91	13.7	6	26	0			2,640	0	36	5	50	H	H	W9:22PM	Th3:12AM	Th9:22AM	Th3:12PM
16	5	80,87	25.4,11.0	17	05	1,100	0	25	0			17	30	E	I	Th3:12AM	Th8:42PM	Th3:12PM	F8:42AM
17	5	75	27.5	12	55	0			0			12	55	I	I	Th8:42PM	F9:37AM	F8:42AM	F9:37PM
18	6	74	27.5	12	55	1,100	0	25	0			13	20	I	J	F9:37AM	F10:57PM	F9:37PM	Sa10:57AM
19	5	81	18.5	8	20	0			0			8	20	J	J	F10:57PM	Sa7:17AM	Sa10:57AM	Sa7:17PM
20	1	81	7.3	3	21	0			0			3	21	J	J	Sa7:17AM	Sa10:38AM	Sa7:17PM	Sa10:38PM
21	1	82	12.02	7	20	1,100	0	25	0			7	45	J	K	Sa10:38AM	Sa6:23PM	Sa10:38PM	S6:23AM
22	1	82	27.0	12	46	0			0			12	46	K	K	Sa6:23PM	S7:09AM	S6:23AM	S7:09PM
23	3	83	5.0	2	21	1,100	0	25	0			2	46	K	L	S7:09AM	S9:55AM	S7:09PM	S9:55PM
24	4	83	11.75	5	31	0			1,110	0	15	5	16	L	L	S9:55AM	S3:11PM	S9:55PM	M3:11AM
25	3	85	11.4	5	22	1,100	0	25	0			5	47	L	M	S3:11PM	S8:58PM	M3:11AM	M8:58AM
26	3	86	3.4	1	35	0			0			1	35	M	M	S8:58PM	S10:33PM	M8:58AM	M10:33AM
27	3	86	3.0	1	00	550	0	13	550	0	09	1	05	M	N	S10:33PM	S11:38PM	M10:33AM	M11:38AM
28	4	85	11.2	5	16	0			0			5	16	M	M	S11:38PM	M4:54AM	M11:38AM	M4:54PM
29	1	84	4.4	2	05	1,110	0	25	6,160	1	24	1	06	M	O	M4:54AM	M6:00AM	M4:54PM	M6:00PM
TOTALS			351.0	165	57	13,530	5	08	13,530	3	05	168	00						

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[a] For irrigators getting nikal, net time actually received is actually this figure plus the nikal time.
[b] M = Monday; T = Tuesday; W = Wednesday; Th = Thursday; F = Friday; Sa = Saturday; S = Sunday
[c] H = hours; M = minutes

There are 94 distinct farms on the watercourse, yet only 29 sanctioned turns exist. The authorized discharge is 1.07 cubic feet per second (c.f.s.), according to Irrigation Department records, but the measured discharge was found to be approximately 1.35 c.f.s.

From the sanctioned pakka warabundi table we see that the first irrigator is located in square No. 88 next to the canal outlet, receiving water at sanctioned nakka position A of the map, of 52 minutes per week for a total of 1.9 acres in commanded (irrigated) area. Under Schedule A, when the warabundi rotation starts every other year at 6 A.M. Monday, his turn is from 6 A.M. to 6:52 A.M. Under Schedule B, when the warabundi starts every other year at 6 P.M. Monday, his turn is from 6 P.M. tc 6:52 P.M. We also see from column 17 that he is the only irrigator included in this allotted turn, and from columns 6-9 that he is not entitled to any extra "bharai" or filling time nor to any "nikal" or emptying time of the main watercourse. He is not entitled to any bharai time because no time transpires in filling the watercourse; the watercourse is already filled with water at the start of his turn. This is so because under normal running conditions (i.e., when the canal is not closed and when the last irrigator(s) is not trading his turn with an upstreamer), the last irrigator(s) is completing his turn and utilizing the full continual flow into the main watercourse just prior to the start of the first irrigator's turn.

To make this clear, let us look at the last sanctioned turn in the table, No. 29. We see that irrigators concerned here have a net turn of one hour and six minutes. On Map 4 we see that their authorized nakka is at point O. During their turn the nakkas leading to all the branches (namely, at points A, E, K and M) will be closed allowing the full discharge to run directly to their open nakka at point O.

Assuming the warabundi is running under Schedule A, at precisely 6 A.M., Monday morning, the first irrigator at the head will open his sanctioned nakka at point A and divert the entire discharge into his fields or internal watercourse by closing the main watercourse channel adjacent and slightly downstream from his nakka.

Since a very small area is being irrigated from this first nakka (only 1.9 acres), this farmer can irrigate his fields directly from this sanctioned nakka. But if a larger area was to be irrigated from one sanctioned nakka, such as a complete square of 25 acres, the nakka would discharge into an internal watercourse, off of which other (unsanctioned) nakkas permit the irrigation of separately owned fields or parcels of land.

Returning to the last irrigators on this watercourse, and again assuming operation under Schedule A, we observe that their net turn is a function of an allotted amount of time based on command area (column 5), some additional bharai time (column 7), and some nikal time (column 9) which is subtracted from the sum of allotted command area time and bharai time.

Given that bharai time is additional time given to those irrigators as a form of compensation for filling an empty, dry watercourse, we see that the last irrigators must bring the water from point M to point O where their sanctioned nakka is located, a total of 1,100 feet (five acres) length (column 6). In accordance with the recommended bharai allotment of five extra minutes of turn per acre (Nasir, 1981) the total bharai addition for these last irrigators is therefore 25 minutes (column 7). This time of five minutes per acre is roughly the average time needed for a normal discharge of between one and 2.5 c.f.s. in Punjab to travel (flow) in an unwetted main watercourse.

Nikal time, on the other hand, refers to an already full watercourse, whereby the last irrigators on the main channel, as well as all branches, can empty (or drain off) the remaining quantities present in the watercourse into their sanctioned nakkas once the watercourse is closed upstream. In the case of the last irrigators on the main channel in our example irrigation at point O, their supply of the full canal discharge ends with the upstream closure of the main channel at point A by the first irrigator. However, even though the main channel is closed and the irrigators' turn officially ends, there is still water present in the main channel which can be emptied or drained off into these last irrigators' fields. Furthermore, this water is legally the property of these last irrigators, to which only they are entitled (Nasir, 1981).

Nikal time is normally calculated at the rate of three minutes per acre length (Nasir, 1981), as the estimated flow time for water to travel in a wetted perimeter. Consequently, for the last irrigators in our example, who are entitled to emptying the water in the main channel of length 6,160 feet (28 acres, column 8), their nikal time is calculated as one hour and 24 minutes (column 9). This time is deducted from their allotted time based on CCA of two hours and five minutes.

It is important to note that whereas the nikal time is deducted from the allotted time based on CCA, and does not appear in the net turn calculation, it is a vital portion of net time from the farmer's point of view. The approximate time actually received by these "last" irrigators is the net time appearing in column 10 plus the nikal time in column 9. In fact, having the right to nikal is a highly valued asset, and many of the water disputes between tail farmers on main channels and branches are related to last turn and last irrigator status.

Tail farmers perceive the quantity (volume) of water received from nikal to be higher than that received under normal irrigation. That is, since relatively more water is lost over time (on a per minute basis) in wetting a dry perimeter (as reflected in bharai time of five minutes per acre length of 220 feet) than in transporting water through a wetted perimeter (as reflected in nikal time of three minutes per acre length), more water may be received per turn on a per acre basis by receiving nikal rather than bharai alone. Because this perception is widespread (it is also reported by Malhotra, 1980), it is reasonable to expect that on a given main channel or branch, more water is being received per acre by "last" irrigators than by other, nearby tail irrigators not receiving nikal.

With this understanding of bharai and nikal we are now in a position to look at the warabundi scheduling for the watercourse as a whole. From the sanctioned warabundi table we see that all net turns must total to 168 hours, the total available hours in a full week, as shown in column 10. The total nikal time allotments are summed (column 9), and this total is added to 168 hours; similarly the total bharai time allotments are summed (column 7), but this total is then subtracted from the sum of 168 hours and nikal time. This leaves the total available time to be alloted to all the sanctioned nakkas and/or turns on a per acre basis.

In our example, this total to be equitably allocated to all sanctioned turns is 165 hours and 57 minutes (168:00 + 3:05 - 5:08 = 165:57). The way of determining average time per acre is to divide time available by the total CCA. The average time per acre in this example is 28.37 minutes ($\frac{165.95 \text{ hours}}{351 \text{ acres}}$).

Irrigation Water Transactions and Trading

The Canal and Drainage Act (Nasir, 1981) states that it is illegal to sell or sublet the whole or any portion of one's authorized right to canal water under pakka warabundi without the permission of an Irrigation Department official. The one exception to this is when one's canal water right is sold simultanesouly with the land to which the water right applies. This has been expanded in case law (Nasir, 1981) to a general prohibition of any exchange of canal water. There are no restrictions, however, on sales of tubewell water. It is possible that the law was passed (in 1873) to give the govnrnment authority to prosecute in the event of inappropriate (e.g., coerced) exchanges, and ignored otherwise.

Despite these legal prohibitions, irrigators do trade canal water turns, and occasionally sell and buy canal water. When a tubewell is present, they may also infrequently trade canal water for tubewell water (see, for example, Lowdermilk, et al., 1975 and 1978, and Gustafson and Reidinger, 1971). When two or more tubewells are present on a watercourse, the owners of these tubewells could trade tubewell water with each other, although there is little incentive for doing this unless one of the tubewells is out of order and tubewell water is desired on loan.

The primary motivating factor behind trades is to gain more control over water supplies in response to crop-water requirements; borrowing from others to supplement one's own, given supplies during periods of relatively high water demand, and lending to others during periods of relatively low demand.

Since no formal market in water rights exists, irrigators also seek to reduce risk by trading. By establishing a pattern of trading with a number of other irrigators, one can increase the chances of being able to borrow some water from others during periods of high water requirements. But to gain this level of relative certainty, one must accommodate the demands of others whenever possible; refusal to trade with a fellow irrigator may mean rejection of one's own request from this irrigator at some other time.

Given the same general cropping patterns on a given watercourse, and roughly the same water requirements per cropped acre, the extent of trading cannot be too great. That is, although a primary motivation for trading exists during periods of high water requirement and demand whenever crop stresses are high, the extent (and volume) of trading must be constrained by overall supplies available. Moreover, the scope for trading depends upon variation of stress conditions from farm to farm.

This may, in fact, vary due to weekly variations in the status of water stored in a given field. The capacity of soil to store water lends a degree of flexibility. At the beginning of any week different fields will have different quantities of water stored in their soils. If a particular farmer is caught with low soil moisture in a field with a vulnerable crop, in a week which has particularly hot, dry weather, he may be able to borrow some water from farmers whose more sensitive crops are buffered by high soil moisture. Thus, on a week-to-week basis, there should be scope for farmers to gain flexibility through trading since their soil provides a small but important source of storage.

The nature and extent of irrigation water sales and exchanges, and their significance in both reducing risk in the timing of water supplies and promoting farm productivity, have largely been ignored. The fact that water sales and exchanges exist in spite of the existing legislation is an anomoly that officials and policy makers choose to ignore. Irrigation officials and the local courts will ordinarily not enforce the edicts against sales and trading unless it can be proven in a case to their satisfaction that the water transactions between two or more farmers is harming any other farmer.

It is notable that water transactions are largely restricted not so much by legal prohibitions but by the irrigation system itself, and that the degree of restriction depends upon the type of warabundi in practice. The irrigation system provides underpriced surface water to joint property watercourses, and a warabundi system allocates this water through a rotation cycle of turns to each farm location in the command area in proportion to the size of farm. The water is taxed indirectly through abiana (see Glossary), but it is really a direct tax on farm production that, in itself, does not encourage the efficient use of water. At any rate, the current system, with its general lack of storage capacity and discouragement of private sector efforts in irrigation water control, is not generally conducive to an organized water market and resulting demand system. Trading and cash transactions in canal water are, therefore, restricted in scope, taking place between individual irrigators whenever and wherever feasible.

Transactions under these conditions are made very difficult due to the prohibitive information and control costs involved. Pakistani canal water irrigators with farms located on watercourses may become potential traders several times throughout the two cropping seasons in the face of periodic shortages of canal water received in relation to crop stress situations and crop-water requirements. But their potential to meet these extra requirements through trading is often limited by uncertainty, information costs, and transaction costs: in not knowing where water surpluses in the system may exist, in not being willing to incur the costs involved in both discovering where they are, and in procurring them for use. In their view, these costs may be higher than the value of water obtained.

Trading within Warabundi

The potential for water transactions, and trading in particular, is further restricted by pakka warabundi, which was ingeniously designed to economize on managerial and administrative resources in the face of formidable control and information problems inherent in large water allocation systems.

The potential for trading is greater on kachha warabundi watercourses where historically an official, farmer-employed "time-keeper" could help to bring potential traders together, and facilitate a trade by readjusting the turns of intervening irrigators. Although the use of time-keepers on all watercourses and the institution of kachha warabundi on the great majority of Punjabi watercourses are largely things of the past, for reasons explained above, kachha warabundi has managed to survive on the smaller watercourses with generally fewer than 20 irrigators per watercourse. As also indicated above, however, the majority of pakka warabundi watercourses are actually a combination of pakka warabundi on the main watercourse and kachha warabundi on the internal watercourses. That is, whereas turns are fixed for each sanctioned nakka on the main watercourse, turns are very seldom fixed for each irrigator sharing this common fixed turn and sharing a miniature system of internal watercourses within each square.[12] This system of combining pakka warabundi on the main watercourse and kachha warabundi on internal watercourses (i.e., within the squares) is sometimes also referred to as "rozwari."

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[12] As an aside, the fixation of turns within a square is in practice an extension of "khatewar," and not "pakka," warabundi. In khatewar warabundi one turn is allocated per irrigator per rotation cycle irrespective of land fragmentation and multiple land holdings of an irrigator on the same main watercourse. Within a square an irrigator can also have several land holdings in different positions and even irrigated from different branches of an internal watercourse. If this is the case, then an irrigation official could only sanction turns within a square under pakka warabundi by first sanctioning the internal watercourse (including it as an extension of the main watercourse), sanctioning nakkas inside the square, and then sanctioning a turn to each nakka (and parcel!). This would be a very detailed and laborious job, and would also violate the guidelines set up in the Canal and Drainage Act, limiting government interference and involvement below the outlet. Therefore, if serious disputes warrant the allocation of sanctioned turns within a square, officials normally assign a fraction of the joint turn to each irrigator in proportion to total size of holding within the square, in the "khatewar" style.

It is also interesting to note that "internal" bharai and nikal times can also be taken into account on internal watercourses in much the same way as on main watercourses. As on main watercourses, bharai and nikal times can be allocated by fellow irrigators on an internal watercourse, and turns can follow a fixed pattern. However, because the distance and number of irrigators involved are so small, these compensation times are usually ignored on internal watercourses.

The irrigators sharing a common sanctioned turn and set of internal watercourses on a pakka warabundi (main) watercourse are usually very small in number (i.e., ten or less in the Punjab, with an average of about five farmers in full 25+ acre squares), are often related (due to subdivisions of original square holdings within an extended family from generation to generation), and typically have an established pattern of cooperation in allocating sanctioned turns and bharai and nikal times, maintenance of both main and internal watercourses, cropping input procurement and use, etc. Thus, their scope for trading among each other is very high, and little problem is encountered in adjusting the turns of intervening irrigators to permit a trade.

A Typical Trade of Canal Water Turns

To illustrate a typical trade, applicable to any type of watercourse or warabundi, assume two partners in a trade are separated by two intervening irrigators on a watercourse. The upstream trader is designated as i and the downstream irrigator as i+3. The two intervening irrigators, also with canal water turns, are designated as i+1 and i+2, respectively, proceeding in a downstream direction. Further assume that the acreage parcel or farm sizes for each of these four cultivators are the same and that their sanctioned turns based on acreage size are two hours each per week, ignoring for the moment any relevant bharai and nikal times. Irrigator i+3 wishes some extra water this particular week and has struck an agreement with irrigator i to borrow one hour's worth of i's turn, with an understanding (often an "unspoken" agreement) that i is entitled to reclaim his lent out hour's worth of turn at some future time. To bring about the exchange, however, irrigator i+3 must also enlist the cooperation of irrigators i+1 and i+2 to slightly adjust the timings of their turns from the predetermined warabundi schedule. The general pattern of an exchange of this type is for irrigator i to begin his turn on schedule, but to stop one hour before the end of his turn and release the water flow in the watercourse over to i+1 one hour earlier than the usual time. Irrigators i+1 and i+2 take their respective turns in order, with the slight one hour forward adjustment in time. At the end of i+2's turn, i+3 can then take his regular turn plus the extra hour passed on from i. At the end of three hours turn he will then turn the water over to irrigator i+4 *at the normally scheduled time*.

The transfer from i to i+3 is now complete and irrigator i may or may not reclaim his hour of turn. If he does, it is called a trade or exchange; if not, it is called a gift. If he lends one hour and gets back one hour it is called a one-to-one exchange, and the net effect on total supplies to each irrigator is zero; however, in terms of productivity of water we assume that the net effect of any trade is positive for all traders.

To return to our example, let us assume that irrigator i wishes to reclaim the hour of turn lent to i+3. He will request this return of one hour in relation to his own, as well as irrigator i+3's, crop requirements. If the terms of the trade were for i to lend to i+3, and, for example, for i+3 to return the hour of borrowed water the following warabundi cycle, then i will likely reclaim his hour regardless of whether i+3 is in dire need of his full turn or not. However, if the terms of trade are more loosely fixed then i will reclaim his hour more or less at i+3's convenience; although, of course, there is an incentive for i+3 to readily comply with i's wishes in order to not adversely affect the potential for further trades.

To complete the exchange, i will, with the consent of i+1, i+2 and i+3, take his regular turn plus the one hour. Then i+1 and i+2 will take their respective turns, but one hour later than usual. Irrigator i+3 will receive a reduced turn of one hour, and i+4, will, again, begin his turn at the regularly scheduled time.

The Nature and Extent of Canal Water Trading

Based upon sampled farmer responses to questions regarding trading, several interesting pieces of information emerged. Table IV-2, below, summarized many of these data. All farmers trade approximately six times as many partial turns as full turns, but active traders trade four times as many full turns as inactive traders. The lower limit on trades is six minutes but the upper limit ranges from ninety-three minutes for active traders to only twenty-nine minutes for inactive traders, with the upper limit for all farmers fifty-two minutes. Farmers trade with an average of three to four others.

Tables IV-3-IV-6, below, present other data relating to trading partners, trading periods (months), constraints on trading of canal water turns and constraints on trades between canal water and tubewell water. Since only six sampled farmers reportedly traded canal water for tubewell water, and always on a one-to-one basis of exchange (i.e., one unit of canal water for one unit of tubewell water), the majority of constraints on trading canal water for tubewell water presented here relate to non-traders of this type. These are frequency tables so more than one response per sampled farmer is possible.

Table IV-2. Reported per Farmer Nature and Extent of Trading in Canal Water Turns, Including Active and Inactive Traders, 1980-81.

Variable	All farmers	Active traders	Inactive traders
No. of Observations	129	42	71
Mean No. of Partial Turns Traded	6	7	6
Mean No. of Full Turns Traded	1	4	1
Mean No. of Hours Traded	5.3	12.4	2.2
Mean Percent of Warabundi Time Traded	6.3	16.5	2.5
Mean No. of Farmers Traded With	3	4	3
Mean Time Limits on Trades			
Lower Limit (minutes)	6	7	6
Upper Limit (minutes)	52	93	29

Table IV-3. Frequency of Sampled Farmer Responses: Relation of Traders, 1980-81.

Categories	Frequency	% of total
Friends, neighbors and relatives inside square	110	75
Friends, neighbors and relatives outside square, but nearby	32	22
Others, far away	5	3
Total	147	100

Table IV-4. Frequency of Samples Farmer Responses: Trading Periods (months), 1980-81.[a]

Categories	Frequency	% of total
March-April	13	6
May-June	102	44
August-September	11	5
October-November-December	108	36
Total	234	101[b]

[a] More than one response per sampled farmer is possible.

[b] Does not add to 100 due to rounding.

The most frequent trading partners are irrigators within one's own square, commonly serviced canal water by one common sanctioned nakka outlet which leads to a series of smaller, internal watercourses. Some trading goes on with other nearby irrigators outside one's own square, but virtually no trading goes on with irrigators far away from the squares immediately preceding or following one's own on the main watercourse.

The most frequent periods of trading in the Faisalabad area are the hot, pre-monsoon summer months of May and June, as well as October-November-December. May and June are the months when kharif crops of fodder (usually maize and jowar sorghum) are receiving heavy pre-planting irrigations and first irrigations after planting, and major sugarcane crops are receiving early post-planting irrigations. In October to December, major wheat and rabi fodder (typically berseem) are receiving heavy pre-planting and early, post-planting irrigations. Considerably less trading goes on in March and April, when land is being prepared for sugarcane planting, and August and September, when land preparation for maize grain planting is taking place.

It may also be mentioned in this chapter that these are the periods of heaviest tubewell water application as well.

Obviously, the greatest perceived constraint on canal water trading (i.e., constraints on any trading for non-traders, as well as constraints on additional trading for traders) is "non-cooperation of intervening farmers," who may refuse to adjust their turns ahead or behind in time to accommodate potential (distant) traders.

Although only six sampled farmers actually traded canal water for tubewell water, or vice-versa, always on a very small scale, all farmers expressed their opinions on trades of this nature. Easily the largest perceived constraints are "canal water is better quality" than tubewell water, in that canal water contains less salts and more sediments or silt (which farmers find useful in adding to topsoil and facilitating bullock-and-tractor-related farm operations) and "no spare canal water" to trade, also apparently expressing an aversion to trade away any supposedly superior quality canal water.

Regression analysis also reveals that trading is inversely related to farm size. Equation 1, below, indicates percent of time traded is only 6 percent higher on smaller farms, but the estimated coefficient value is significant at the 1 percent level according to the t-ratio.

$$\text{\% of Time Traded} = 10.84 - \underset{(3.00)^{***}}{.65}\ \text{Size of Farm (acres)} \qquad \text{(IV-1)}$$

$$r^2 = .07 \qquad n = 126 \qquad F = 8.99^{***}$$

There are two possible explanations for this observed tendency. First, frequent and relatively small time and volume trading is proportionally more significant with regard to shorter turns and smaller farms. Larger farms have more flexibility and degrees of freedom within the farm with respect to stress and crop-water requirements than smaller farms, even within the same crop type. Also, irrigation of larger farms with greater volumes of water per turn is more difficult than irrigating with smaller absolute volumes per turn. That is, it is more difficult while irrigating larger areas of land to ensure that water is equitably applied to all fields and all parts of each smaller field. This may, in part, decrease the incentive to obtain more water through trading.

Table IV-5. Frequency of Sampled Farmer Responses: Constraints on Canal Water Trading, 1980-81.[a]

Constraints	Frequency	% of total
Non-cooperation of intervening farmers	106	65
No need to trade; full canal water turn needed; tubewell water plentiful and easy to obtain	37	23
Others refuse to trade; different length of turn	15	9
Length or slope of the watercourse	6	4
Total	164	101[b]

[a] More than one response per sampled farmer is possible.
[b] Does not add to 100 due to rounding.

Table IV-6. Frequency of Sampled Farmer Responses: Constraints on Trading Canal Water for Tubewell Water (or vice versa), 1980-81.[a]

Constraints	Frequency	% of Total
Non-cooperation of intervening farmers	14	9
Canal water is better quality	64	42
No spare canal water to trade	45	30
No spare tubewell water to trade	8	5
No need to trade	4	3
Slope of watercourse; traders on different branches	16	11
Total	151	100

[a] More than one response per sampled farmer is possible.

The Process of Watercourse Improvement

The final option considered here for farmers in canal irrigated areas to gain control and flexibility over the use of water supplies is watercourse improvement, conducted primarily by provincial On-Farm Water Management (OFWM) Pilot Project Cells of the Pakistan Ministry of Agriculture.

The general procedure for watercourse improvement, as experienced on sampled watercourses, is for one of the OFWM employees to approach the influential farmers on a watercourse in the general OFWM project area about the prospect of improving the watercourse. Because this is a relatively new and often misunderstood project, farmers seldom take the first step of approaching the OFWM personnel themselves.

After the initial contact farmers are required to provide the signatures of some two-thirds of the concerned farmers on a given watercourse signifying the consensus approval of the improvements to come. Farmers must also collect money in advance for hired labor expenses.

Under the guidance of OFWM personnel equipped with surveying instruments, the work of earthen improvement of the main joint-farmer-property watercourse commences from the canal outlet to the end of the watercourse. All trees, bushes and vegetation within about five feet either side of the channel are removed, the banks are dug up, the channels are straightened, and the banks and freeboards are reshaped to specified dimensions with considerable earth compaction.

At the completion of this laborious work, hired masons and laborers are brought in to install prefabricated locally-produced concrete outlet structures at specified points along the watercourse, presanctioned by the Irrigation Department, to allow the canal water to flow from the main, joint property channel to farmers' fields through internal watercourses. These masons also generally line sections of the main watercourse with bricks and a layer of cement where water losses are considered most severe.

The project provides all cement, bricks and concrete outlet structures free of cost to the farmers. Due to perceived cost-to-the-project considerations the lined section has generally been restricted to only 10 percent of the total main watercourse length. This has been increased to a maximum of 30 percent as of July 1981 under the new World Bank-funded status (Wor Bank, 1982). The masons will also construct specified numbers of concrete buffalo wallows (small tanks for the required periodic bathings of water buffaloes) and culverts (small overpasses). Justification of watercourse lining is that it serves as an effective means of extending the life of the overall improvement. To date little attention has been paid to the question of optimal channel lining (for example, see Clyma, et al., 1981, Ali, 1980, and Malhotra, 1980). It should also be noted that the internal watercourses, and often times some or all of the branches of the main channel, are left totally unimproved, again due to perceived cost considerations.

Summary

In this chapter the macro system of canal irrigation, chaks and watercourses was described as purely background material. Detailed descriptions of irrigating with canal water, through warabundi, and tubewell water, using an example from one of the sample watercourses of this research, demonstrated the complexity of existing institutions to allocate water on watercourses. The fact that pakka warabundi on the main watercourse is typically comprised of mini-systems of both pakka and kachha warabundi on internal watercourses, raises questions of relative impacts on productivity of the two basic types of warabundi.

Discussion of the agronomic environment, on the other hand, raises issues of consumptive water use requirements of major crops in relation to periodic and unpredictable shortfalls in water supplies. Both tubewell water selling activities and added canal water supplies obtained through trading are seen as potential means to overcome both seasonal and transient peak demands for water. Trading canal water turns is explained in some detail because of a lack of description in the literature.

We continue this discussion of gaining control over water supplies to help meet peak demands in Chapter V by presenting and interpreting results with regard to three indigenous farm methods of control. The detailed description of these methods in Chapter IV enables the formulation and testing of tentative theories based on a relatively small number of sample observations.

CHAPTER V

INDIGENOUS METHODS USED BY FARMERS TO INCREASE CONTROL OVER WATER SUPPLIES

It was seen in Chapters III and IV that trading of partial turns and purchase of tubewell water are common in the 20 watercourses visited, and that kachha internal warabundi is also a common feature. Each of these practices add some measure of flexibility to farmer allocation of water. This chapter is devoted to a statistical analysis of the relationships between each of these practices and productivity (as calculated by gross income per acre), and to interrelationships of the measures themselves. Another method, watercourse improvement, is the object of a USAID, World Bank and Government of Pakistan program to improve conveyance efficiencies of Pakistani watercourses. This chapter is devoted to analysis of the three indigenous methods while watercourse improvement will be the subject of Chapter VI.

Interpretation of Statistical Tests of Significance

The nature of sampling and data collection procedures has yielded non-random samples, limiting the interpretation of statistical tests and levels of significance throughout Chapters V, VI and VII. Only with regard to the estimation of conveyance efficiencies for improved and control watercourses did this study assume a hypothesis testing nature with a predictive or verifiable theory. This is because the set of improved watercourses selected was based on a random sample. The predictive theory tested was that conveyance efficiencies are greatly (and significantly) increased as a result of watercourse improvement (see Chapter VI for tests of this theory).

Significance levels and tests for other relationships will be reported throughout these chapters but always with an essential reservation: results from this study cannot be strictly inferred to a larger population of watercourses or farms in the province. The reported t- and F-ratios, and corresponding significance levels are intended only to effectively demonstrate the relative strengths of correlations and interrelationships as related to this specific not precisely – random sample.

Interrelationships

One reason for treating the indigenous methods together is the a priori likelihood that they are interrelated. In Chapter IV it was shown that the warabundi system and the physical layout of watercourses impose limits on timing of purchases of tubewell water. The same environment limits the scope for trading canal water turns allocated through warabundi. However, the availability of tubewell water can decrease the risk inherent in lending or borrowing partial turns. This is because farmers who are able to purchase tubewell water on short notice can more than compensate for partial turns foregone. Therefore, tubewell water acts directly to reduce the risk of plant stress by making large amounts of water available on short notice; and it also acts indirectly to reduce risk by increasing willingness to trade, which is a form of flexibility.

To illustrate with an example, let us assume a farmer (Mr. A) operating an average size farm or parcel of four acres in the Faisalabad area obtains weekly allocation of canal water through pakka warabundi of two hours (30 minutes per acre), and that he also has easy access to tubewell water by purchasing from a private tubewell owner. This farmer is approached by a neighboring farmer (Mr. B) who requests to borrow 30 minutes of A's canal water turn during a period of predictably high evapotranspiration. Since tubewell water is available to A on short notice (i.e., typically during one's canal water turn), he will likely lend this amount of canal water to B, with the security of knowing that if ususually high, unpredictable evapotranspiration and stress conditions prevail and A is suddenly caught short of canal water supplies, he can obtain tubewell water to satisfy crop consumptive use requirements.

The practice of kachha internal warabundi can also decrease the risk of obtaining timely quantities of tubewell water on short notice by the fact that relatively more ease is possible in adjusting the turns of other irrigators, on the same internal watercourse, to coincide with one's own needs. This flexibility is favorable to tubewell water sales because unforeseen circumstances may require adjustment of turns on short notice to effectively utilize tubewell discharges.

For example, an irrigator (Mr. A) may wish to purchase some tubewell water during his predetermined warabundi turn of canal water, but may not be able to obtain the required quantity of tubewell water precisely when desired because of unforeseen circumstances. If he practices kachha internal warabundi in cooperation with other irrigators on the same internal watercourse, he may be able to obtain flexibility from fellow kachha warabundi irrigator (Mr. B) whose turn falls after A's that particular rotation week. Mr. B can take his turn before A, until the tubewell is again able to discharge water into the watercourse destined for A's fields. This is not to say that pakka internal warabundi irrigators cannot strike similar flexible arrangements for obtaining tubewell water with neighboring farmers, but only that it will be easier for kachha internal warabundi irrigators who have an established precedent of cooperation with neighbors. It should also be noted that this practice of adjusting turns and timings constitutes trading, by definition.

Trading is conceptually related to the practice of kachha internal warabundi even without the presence of one or more tubewells in a watercourse command, or tubewell water use per se, because of this relative ease in pursuading other neighbors using the same internal watercourse to adjust turns to meet individual needs.

With these conceptual linkages outlined, we are now in a position to examine both the isolated and joint effects of these indigenous methods of augmenting water control on productivity. Differences in mean per acre gross income for the different sub-categories employing various water control options can be seen in Table V-1. Similarly, differences in each of the explanatory variables, cropping intensity and percent of high water using crops grown can also be seen.

Following discussion of the overview of data relating to the various indigenous methods of farmer control, results from production function analyses of the direct impacts of control methods on productivity are presented and discussed. Results from tests on the types of interrelationships between different control options are also presented and interpreted.

An Overview of Indigenous Methods of Control

This section highlights simple mean and variance data relating to the three methods of indigenous farmer control over water supplies appearing in Table V-1 below. This table divides the production-related data into different sub-categories, beginning with a contrast between "tubewell water users" and "non-tubewell water users." The sub-category of tubewell water users is then sub-divided into three sets of sub-sub-categories of (1) actual tubewell owners and tubewell water buyers, (2) singly owned tubewell users and joint property tubewell users, and (3) electric-powered tubewell users and diesel-powered tubewell users.

Other important sub-categories of active and inactive traders and kachha and pakka internal warabundi users follow the various tubewell water sub-categories. Finally, mean and standard deviation data for the entire sample are presented.

Percentage differences in contrasted sub-sample means are also displayed, and significance (confidence) levels are indicated where applicable using the students' t-test.

Tubewell water use and productivity

The contrast between tubewell water users and non-tubewell water users is clear-cut: tubewell water users realize higher per acre gross incomes on average and use a great deal more per acre cash inputs and

Table V-1. Sample Sizes, Mean Values, Percentage Difference in Contrasted Sub-sample Mean Values and Standard Deviations for Sub-samples of Tubewell Water Users, Traders and Users of "Internal" Warabundi.

		Gross Income per acre			Canal Water Use per acre			Tubewell Water Use per acre			Cash Input Expenditure per acre			Labor Use per acre			Bullock Power Use per acre			Tractor Power Use per acre			Cropping Intensity			% of high water Using Crops Grown		
Sub-sample category	No. of observations	Mean (Rs.)	% diff. in means	Standard deviation	Mean (Ac. In.)	% diff. in means	Standard deviation	Mean (Ac. In.)	% diff. in means	Standard deviation	Mean (Rs.)	% diff. in means	Standard deviation	Mean (Man-days)	% diff. in means	Standard deviation	Mean (Hrs.)	% diff. in means	Standard deviation	Mean (Hrs.)	% diff in means	Standard deviation	Mean (%)	diff in means	Standard deviation	Mean (%)	% diff. in means	Standard deviation
Tubewell Water Users	60	3517	20**	1744	25.6	-3	8.9	17.0	∞***	18.0	381	24***	151	75.5	2	37.0	39.2	-23**	24.2	2.9	35**	2.0	170	7	27	37	6	22
Non-tubewell Water Users	69	3018		1081	26.3		9.5	0		0	309		156	73.8		37.8	48.1		16.3	2.1		1.7	160		25	35		17
Tubewell Owners	10	4659	34**	2029	25.2	-4	6.7	31.4	122***	21.9	388	1	86	75.5	-1	46.4	40.8	5	26.6	3.5	[illegible]	2.1	184	10	23	45	27	20
Other Tubewell Users (Buyers)	50	3475		1632	26.2		8.6	14.2		13.3	385		158	76.2		35.6	38.9		24.2	2.8		2.0	168		28	36		22
Single Family Owned Tubewell Users	32	4019	27*	1738	23.5	-18	7.1	20.5	58*	22.6	358	-14	117	83.4	25*	40.4	43.1	24	25.3	2.7	-22	2.0	174	5	29	38	6	25
Cooperatively and Joint Family Owned Tubewell Users	28	3167		1629	27.8		10.3	13.0		9.3	409		140	66.6		31.0	34.9		22.4	3.3		2.6	166		26	36		19
Electric-Powered Tubewell Users	44	3688	8	1718	24.3	-19	6.8	18.7	49	19.1	386	5	159	74.5	-5	32.2	41.9	31	23.5	2.6	-32	1.8	169	-2	28	36	-8	23
Diesel-Powered Tubewell Users	16	3422		1856	29.0		12.8	12.5		13.7	368		129	78.4		48.5	31.9		25.2	3.5		2.5	173		26	39		20
Active Traders	42	3828	26***	1759	24.5	-7	8.0	11.3	100*	19.5	351	5	131	73.2	-4	39.7	41.3	-13	18.9	2.3	-9	1.9	168	3	25	35	-3	19
Inactive Traders	71	3043		1196	26.4		8.9	5.7		12.3	334		150	76.2		35.5	46.8		21.4	2.5		1.9	163		26	36		18
"Internal" Kachha Warabundi Users	77	3343	4	1451	25.4	-5	7.3	9.0	42	13.6	386	18	339	74.6	2	35.4	43.4	-6	22.4	2.4	0	1.9	185	1	25	38	19	19
"Internal" Pakka Warabundi Users	52	3228		1473	26.7		11.2	6.3		16.7	[illegible]		165	73.2		40.0	46.1		19.6	2.4		1.8	164		28	32		20
Total Sample	129	3297		1453	26.0		9.2	7.9		14.9	344		198	74.0		37.3	44.0		20.7	2.4		1.9	164		26	36		19

*Significance at the 90 percent confidence level, two-tailed t-test.
**Significance at the 95 percent confidence level, two-tailed t-test.
***Significance at the 99 percent confidence level, two-tailed t-test.

tractor power than non-tubewell water users, and less bullock power per acre.

Within the sub-category of tubewell water users, a much sharper contrast is exhibited between actual tubewell owners and other tubewell water users (buyers). Both mean per acre gross incomes and tubewell water use are higher on tubewell owning farms. Obviously actual sampled tubewell owners can exert more control over water supplies with favorable impacts on productivity.

The same general pattern of relationships as above is demonstrated in contrasts of users of singly owned tubewells versus users of joint property tubewells. Both per acre gross incomes and tubewell water use are much higher for users of singly owned tubewells.

It appears likely that users of singly owned tubewells exercise more control over tubewell water supplies than users of joint property tubewells. As a conjecture, this may be largely due to increased efficiency experienced in the operation of single owner tubewells, supplying consistently more tubewell water, more frequently, with positive productivity implications to all users. This issue will be explored in more detail below with further analyses using production function and regression techniques.

Surprisingly, there is no great difference in mean per acre gross incomes or tubewell water use between users of electric-powered and diesel-powered tubewells. As explained in Chapter III, energy price differentials between electricity and diesel were very high in 1980 81. In fact, the average per hour price for electric tubewell water in the sample was only eight rupees, against an average price ot twenty rupees per hour for diesel tubewell water. Apparently, energy price differentials were not great enough to have major effects on either tubewell water use or productivity. This result is consistent with the idea that tubewell water is being 'rationed' (i.e., used to capacity). This issue will be explored in more detail below, with the discussion of marginal value products and opportunity costs of key inputs.

However, other possible reasons for these phenomenon may be: (1) a relative lack of sample observations for diesel-powered tubewell users in comparison to a large number of observations for electric-powered tubewell users; and (2) the fact that diesel tubewell users use 32 percent more diesel tractor power per acre (but 31 percent less bullock power per acre) than electric tubewell users, with the implication that somehow the joint effect of diesel-powered tubewells and tractors partially offsets the effect of lower-cost electric-powered tubewells.

There is no general pattern demonstrated between tubewell ownership arrangement and power source. Of a total of fifteen sampled tubewells which regularly engage in tubewell water selling activities, six are singly owned and electric, four are jointly owned and electric, three are singly owned and diesel, and two are jointly owned and diesel.

Trading and productivity

Comparisons are also made here between groups of "active" and "inactive" traders. It was discovered that only 16 sample farmers (or 12 percent of the total) do not trade at all, making any statistical comparisons between the groups of (all) traders and non-traders largely inconclusive because of a lack of degrees of freedom in the group of non-traders.

Data in Table V-1 indicate that active traders realize much higher mean per acre gross incomes than inactive traders. Active traders also use considerably more tubewell water per acre.

This last result, in conjunction with analysis of variance results already discussed, suggests that trading is positively related to tubewell water use, and that trading, like tubewell water use, strongly impacts productivity. However, before we pass judgement on these issues and discuss their implications, it would be well to examine the other types of analyses which are used below to address these two indigenous methods of control.

Other simple relationships are suggested by Table V-1 regarding the type of internal warabundi which warrant attention before discussion of more complex issues.

Type of internal warabundi and productivity

Interestingly, differences in mean values do exist between sub samples of users of "kachha" and "pakka" internal warabundi, but t-tests reveal nothing of significance with regard to this particular sample — even with regard to per acre tubewell water use which is 42 percent higher on average for users of kachha internal warabundi.

Obviously, analysis of mean and standard deviations does not represent the whole story, or even begin to critically examine the question of how tubewell water use, trading and kachha internal warabundi relate to farmer control of variability of productivity (as measured by gross income per acre).

Production Function Analyses

A more sophisticated test of the relative impacts of methods of increased farmer control and flexibility on productivity is production function analysis. Covariance analysis (Fisher, 1970, and Johnston, 1972) is used to test for differences in gross value production functions between two respective sub-samples. Covariance tests ask the question: Has the impact of farmer control method significantly changed the production function?[13]

One measure of the effects of method on control and flexibility is the percent of variation explained by farm inputs under each farmer option, through interpretation of computed R^2 values. Another measure is through analyses of individual estimated coefficient values.

Separate log-linear Cobb-Douglas gross income (or gross value of production) functions were estimated for separate sub-samples, and a joint production function was also estimated for the combined sample.

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[13] The covariance test is specified by Fisher (1970), for cases when the number of parameters to be estimated is less than the respective sub-sample sizes, as the computation of an F-ratio, to be compared with a tabular F value with appropriate degrees of freedom:

$$F^* = \frac{(r'r-e'e)/k}{e'e/(N-2k)}$$

where r'r = joint (restricted) sum of squared residuals, without dummy variables, for two or more sub-samples; e'e = sum of the respective sum of squared residuals for the individual sub-samples; K = number of parameters to be estimated; and N = pooled sample size.

This test appears to be a variant of the traditional test of hypotheses involving more than one regression parameter (see, for example, Kmenta, 1971), but with use of an unrestricted model which includes all possible combinations of intercept and slope dummies with the specified independent variables. The degrees of freedom in both F tests are apparently the same, but the user of the covariance test does not have to go through the process of specifying all dummy variables in the unrestricted model.

In addition to the various regressions estimated and displayed below (these permitted the covariance test to be performed), another pooled sub-sample regression equation was estimated when contrasting the paired sub-samples of singly-owned and joint property tubewell water users, active and inactive trading farms and kachha and pakka internal warabundi practicing farms.

The basic model and variables used in analyzing data with regard to the indigenous methods of control are listed below.

$$GIA_i = A \cdot CWA^{X_{1i}} \; TWA^{X_{2i}} \; CIA^{X_{3i}} \; LBA^{X_{4i}} \; BHA^{X_{5i}} \; TRA^{X_{6i}} \; e^u$$

where:

GIA = gross income per acre in rupees (sum of crop yields times prices received)

i = type of farm; i = 1-14

(1 = tubewell water using; 2 = non-tubewell water using; 3 = actual tubewell owning; 4 = tubewell water purchasers; 5 = single-family owned tubewell water using; 6 = cooperatively- and joint-family owned tubewell water using; 7 = electric-powered tubewell water using; 8 = diesel-powered tubewell water using; 9 = canal water trading; 10 = non-canal water trading; 11 = active canal water trading; 12 = inactive canal water trading; 13 = kachha "internal" warabundi practicing; 14 = pakka "internal" warabundi practicing)

A = constant shift term (slope modifier)

CWA = canal water used per acre in acre inches

TWA = tubewell water used per acre in acre inches

CIA = cash inputs used per acre in rupees

LBA = labor used per acre in man days

BHA = bullock power used per acre in hours

TRA = tractor power used per acre in hours

e = natural logrithmic base

u = disturbance or error term

and A, X_{1i}, X_{2i}, X_{3i}, X_{4i}, X_{5i} and X_{6i} are coefficients to be estimated.

This model allows ordinary least squares regression analyses to be computed, for different combinations of sample categories of farms. This particular Cobb-Douglas model was used for reasons of ease of computations, small standard errors of estimated coefficients and high levels of efficiency in predicting outputs for given inputs.

This approach is a modified version of the Lau-Yotopoulos (1971) profit model, tested empirically in the Pakistan context by Khan and Maki (1979). However, instead of using a measure of profit as the dependent variable, a measure of gross (crop-production) revenue was used for simplicity, with generally favorable results. Limitations of standard Cobb-Douglas type models are generally well known but were not an over-riding concern because the objective of the regressions is to test tentative hypothesis which may later be the subject of larger studies.[14]

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[14] Some key references, with relevance to this study, on the special features and limitations of the Cobb-Douglas include: Alcantara and Prato (1973), Lau-Yotopoulos (1971), Khan and Maki (1979), Binswanger (1974) and Sindhu and Baanante (1981) — for variants of the standard Cobb-Douglas; Barr and Horrel (1976) — for mis-specification

Gross value of production function results are displayed in Tables V-2 to V-5, below, with respect to: (1) tubewell water using, non-tubewell water using and all farms; (2) users of single-family owned tubewells, users of joint property tubewells and all tubewell users; (3) active, inactive and all traders; and (4) kachha and pakka internal warabundi farms, and all farms.

Covariance tests indicate that the impacts of single ownership tubewell arrangements and active trading of canal water positively and greatly impact productivity. The impacts of tubewell water use and kachha internal warabundi also positively impact crop production, but their respective degrees of impact are significant only at the 25 percent level in this particular sample.

Contrasts between R^2 values indicate that the percent of explained variation of the models increases somewhat through all control methods. How much of an increase, however, is unknown because the R^2 differences may also be a result of the inclusion of an extra independent variable (e.g., in the case of the tubewell water per acre input for the class of tubewell water users, and no such input for non-tubewell water users) and/or more variation in the dependent variable (GIA) per se.

There are two factors which tend to cause a larger range of dependent variable values, given that the error term is normally distributed. First, for two estimates which are, in fact, similar, the one with the large range about explanatory variables will demonstrate a larger range on the dependent variable, and therefore more explained

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bias; Heady and Dillon (1961) -- for aggregation bias; and Sampath (1979), de Janvry (1972), Johnston (1977) and Koutsoyiannis (1971) -- for simultaneous equation bias.

Table V-2. Regression Coefficients Relating Logarithms of Gross Value of Production per Acre to Logarithms of Various Inputs for a Sample of Tubewell Water Using, Non-tubewell Water Using and All Farms, 1980-81 (Cobb-Douglas Model).

Explanatory variable	Unit	Tubewell water users	All farms	Non-tubewell water users
Canal Water per Acre	Acre Inches	-.02 (.15)	-.01 (.18)	-.02 (.18)
Tubewell Water per Acre	Acre Inches	.13 (2.36)**	.05 (1.78)*	0 (0)
Cash Inputs per Acre	Rupees	.58 (4.07)***	.41 (5.27)***	.30 (3.46)***
Labor per Acre	Man Days	.16 (1.51)	.25 (3.53)***	.26 (2.78)***
Bullock Power per Acre	Hours	.03 (.71)	.07 (2.27)**	.11 (2.37)**
Tractor Power per Acre	Hours	.04 (.39)	.12 (2.08)**	.18 (2.63)**
Intercept		3.47	4.28	4.72
R^2		.43	.35	.35
Overall F-Statistic		6.70**	11.07***	6.78**
Error Sum of Squares/ (n-K-1)		.15	.14	.11
Covariance Test F-Statistic			1.63	
Sample Size (n)		60	129	69
Sum of Non-intercept Coefficients		.96	.89	.83

(Figures in parentheses represent t-ratios.)
*Significance at the 10 percent level.
**Significance at the 5 percent level.
***Significance at the 1 percent level.
K = Number of parameters being estimated.

Table V-3. Regression Coefficients Relating Logarithms of Gross Value of Production per Acre to Logarithms of Various Inputs for a Sample of Irrigated Farms Using Either Single-Family Owned or Cooperatively and Joint-Family Owned Tubewells, and all Tubewell Users, 1980-81 (Cobb-Douglas Model).

Explanatory variable	Unit	Users of single-family owned tubewells	All tubewell users	Users of cooperatively and joint-family owned tubewells
Canal Water per Acre	Acre Inches	.09 (.63)	-.02 (.15)	-.27 (1.19)
Tubewell Water per Acre	Acre Inches	.03 (.51)	.13 (2.36)**	.24 (2.81)***
Cash Inputs per Acre	Rupees	.83 (3.64)***	.58 (4.07)***	.46 (2.64)**
Labor per Acre	Man Days	.003 (.03)	.16 (1.51)	.20 (1.20)
Bullock Power per Acre	Hours	-.05 (.91)	.03 (.71)	.07 (1.20)
Tractor Power per Acre	Hours	-.05 (.38)	-.04 (.39)	-.02 (.12)
Intercept		3.22	3,47	4.58
R^2		.61	.43	.59
Overall F-Statistic		6.31**	6.70***	5.34**
Error Sum of Squares/ (n-7)		.12	.15	.11
Covariance Test F-Statistic			3.40***	
Sample Size (n)		31	60	29
Sum of Non-intercept Coefficients		.85	.96	.68

(Numbers in parentheses represent t-ratios).
*Significance at the 10 percent level.
**Significance at the 5 percent level.
***Significance at the 1 percent level.

Table V-4. Regression Coefficients Relating Logarithms of Gross Value of Production per Acre to Logarithms of Various Inputs for a Sample of Irrigated Farms, Including Active and Inactive Traders of Canal Water Turns, 1980-81 (Cobb-Douglas Model).

Explanatory variable	Unit	Active traders	All traders	Inactive traders
Canal Water per Acre	Acre Inches	-.04 (.31)	-.05 (.48)	.03 (.19)
Tubewell Water per Acre	Acre Inches	.02 (.57)	.05 (1.84)	.02 (.51)
Cash Inputs per Acre	Rupees	.86 (5.94)***	.43 (5.07)***	.34 (3.35)***
Labor per Acre	Man Days	.13 (1.33)	.18 (2.43)***	.25 (2.31)**
Bullock Power per Acre	Hours	-.01 (.16)	.05 (1.61)*	.09 (2.12)**
Tractor Power per Acre	Hours	.04 (.39)	.12 (1.53)*	.13 (1.81)*
Intercept		2.74	4.61	4.42
R^2		.63	.37	.32
Overall F-Statistic		9.63***	10.33***	5.03**
Error Sum of Squares/ (n-7)		.08	.13	.13
Covariance Test F-Statistic			3.38***	
Sample Size (n)		42	113	71
Sum of Non-intercept Coefficients		.98	.78	.86

(Numbers in parentheses represent t-ratios.)
*Significance at the 10 percent level.
**Significance at the 5 percent level.
***Significance at the 1 percent level.

Table V-5. Regression Coefficients Relating Logarithms of Gross Value of Production per Acre to Logarithms of Various Inputs for a Sample of Irrigated Farms with Kachha and Pakka Warabundi Arrangements on Internal Watercourses, 1980-81 (Cobb-Douglas Model).

Explanatory variable	Unit	Farms practicing kachha internal warabundi	All farms	Farms practicing pakka internal warabundi
Canal Water per Acre	Acre Inches	.10 (.79)	-.01 (.18)	-.23 (1.45)
Tubewell Water per Acre	Acre Inches	.02 (.89)	.05 (1.78)**	.10 (2.02)**
Cash Inputs per Acre	Rupees	.56 (5.61)***	.41 (5.27)***	.31 (2.32)**
Labor per Acre	Man Days	.17 (2.04)**	.25 (3.53)***	.32 (2.50)**
Bullock Power per Acre	Hours	.07 (1.84)*	.07 (2.27)**	.08 (1.54)
Tractor Power per Acre	Hours	.09 (1.28)	.12 (2.08)**	.18 (1.61)
Intercept		3.40	4.28	5.15
R^2		.43	.35	.34
Overall F-Statistic		9.02***	11.07***	3.68*
Error Sum of Squares/ (n-7)		.11	.14	.17
Covariance Test F-Statistic			1.50	
Sample Size (n)		77	129	52
Sum of Non-intercept Coefficients		1.01	.89	.76

(Numbers in parentheses represent t-ratio.)
*Significance at the 10 percent level.
**Significance at the 5 percent level.
***Significance at the 1 percent level.

variation. It can be seen from Table V-1 that none of the paired subsamples exhibit sizable and consistent differences in explanatory variable standard deviations. Second, for two estimated relationships with similar ranges about explanatory variables, that relationship with the "steeper" gradient should show the greater explained variation. The slope of the gradient in the case of a Cobb-Douglas function is strongly influenced by the sum of non-intercept estimated coefficient values. This second factor can be thought of as measuring the proportionate change in dependent variable explained variation. On the other hand, the estimated error sum of squares for each relationship divided by (n-K-1) -- where n = sample size and K = number of parameters being estimated -- effectively measures the absolute change in dependent variable explained variation.

The much greater R^2 value, coupled with the lower adjusted error sum of squares (see Table V-4), for active, as opposed to inactive, trading farms certainly appears a large enough difference to suggest that active trading farms have more explained variation in their estimated production function than their counterparts; and, by inference exercise more control over productivity. Similarly, the greater R^2 value and lower adjusted error sum of squares value for practicers of kachha, as opposed to pakka, internal warabundi suggest that kachha internal warabundi practicing farms exercise more control over productivity than their counterparts. However, the larger R^2 value for tubewell water using farms, in contrast to non-tubewell water using farms, is confounded by a higher adjusted error sum of squares value as well. Both sub-categories of tubewell water using farms (see Table V-3) exhibit lower adjusted error sum of squares, but no less than for non-tubewell water using farms.

The elasticities on cash inputs are always higher for the sub-sample which is expected to exercise greater control over water, indicating a complementary relation between water control and fertilizer. However, the elasticities of tubewell water use are always lower or about equal for the sample with hypothetically greater control, perhaps reflecting the greater value of control for those who start with relatively less. Analyses on the efficiency of input use, which follow below, trace the relative impacts on productivity.

Efficiency of Input Use: Derivation of Opportunity Cost

A measure of the efficiency of input use on the average is provided by calculation of the ratio of marginal value product to opportunity cost, and comparison of the ratio to the value of one. Efficiency is implied if the ratio equals one. A ratio less than one shows over-use of the input, and a ratio greater than one shows under-use of the input. These calculations are important because: (1) the marginal value product of cash inputs, in particular, substantially rises with control enhancing activities; and (2) these input use efficiencies have important bearings on policy and further research.

The derivation of marginal value products can be demonstrated with an example. Consider the following log-linear regression equation:

$$\ln Y = \ln a + b_1 \ln x_1 + \ldots + b_n \ln x_n + u$$

Differentiating this equation with respect to x_1 yields (assuming u is the random disturbance term):

$$\frac{\partial Y}{\partial X_1} \cdot \frac{1}{Y} = \frac{b_1}{x_1} \quad \text{or} \quad \frac{\partial Y}{\partial X_1} = b_1 \frac{Y}{X_1}$$

If the output (Y) is expressed in monetary terms, the marginal value product (MVP) of an input (X_1) can be computed from the geometric mean of each input and the output:

$$\text{MVP of } X_1 = \frac{\partial Y}{\partial X} = b_1 \frac{\bar{Y}}{\bar{X}_1}$$

Opportunity costs are computed as follows:

Canal water. The cost of canal water use is generally underpriced if measured by the abiana (indirect irrigation water tax) rates or actual receipts. Furthermore, the opportunity cost for canal water is a function of timing, in relation to tubewell water availability and use. Consequently, during periods of irrigation with tubewell water, the shadow price of canal water may be viewed as approximately equal to the marginal value product of tubewell water use, since at this time canal and tubewell water are perfect substitutes for each other. However, during periods of no, or very little, tubewell water use and active trading, the shadow price of canal water is about equal to the price of tubewell water sold as the upper limit. This assumption is justified by reasoning that irrigators, being generally risk averse, will only buy tubewell water when the value of that water is greater than the market price. (If the value is equal to the price they still will not purchase tubewell water because of risk aversion.) The shadow price for canal water at all other times can be taken as zero.

Using these assumptions, the opportunity cost of canal water can be calculated as the proportion of joint tubewell and canal water use times the derived marginal value product for tubewell water, plus the proportion of sole canal water use in the peak trading months of May-June and October-November-December times the market price of tubewell water. Since these are all variable from sample to sample, opportunity costs for canal water will also differ between samples. In fact, computed values range from 2.7 to 13.5 rupees, but the overall average is 6.60 rupees.

Tubewell water. On watercourses which have one or more private tubewells, the price of tubewell water sold in 1980-81 can be taken as the opportunity cost. Price differences do occur from watercourse to watercourse and season to season, in relation to energy and operation costs and source of power. The average price of electric-powered tubewell water was eight rupees per hour in 1980-81, as reported by forty-six users (both buyers and sellers), or 69 percent of all tubewell water users. The average price of diesel-powered tubewell water, on the other hand, was a significantly higher 20 rupees per hour in 1980-81, as reported by 21 users, or 31 percent of all tubewell water users. The weighted average price of tubewell water in 1980-81 is 12 rupees per hour.

However, simple conversion of this price into acre inch units (e.g., $\frac{\text{Rs. 12 per hour}}{\text{1.19 acre inches per hour}} = 10.08$ rupees per acre inch, where 1.19 is the average sample tubewell discharge) would be an incorrect calculation of opportunity cost befause it ignores watercourse conveyance losses. Since sample farmers were located at different relative watercourse positions, average loss rates must be used to estimate actual acre inch flow rates. It was demonstrated in Table V-1, above, that per acre loss rates differ between improved and control watercourses, although not by as much as originally hypothesized. The overall average percentage loss from head to tail is 37 percent. The average overall (disregarding relative watercourse position) flow can then be calculated as $\frac{1.19 + (1.19 \times .63)}{2} = .97$ acre inches per hour. The average overall opportunity cost can then be calculated as 15.38 rupees per acre inch.

If analysis is performed with respect to relative watercourse position, however, the average flow rates for head, middle and tail farms are 1.19, .97 and .75, respectively, since the majority of tubewells are located at the head. The average opportunity costs, then, for head, middle and tail farms are, respectively, 10.08, 12.37 and 16.00

Cash inputs. Since cash inputs are measured in rupees, the appropriate opportunity cost is simply 1 + i, where i is the interest rate charge on capital use. The total expenditure of all sampled farms on fertilizer was 177,986 rupees (or 84 percent of total cash inputs expenditure); and the total expenditures on the other components of cash inputs, seeds and pesticides, were only 21,607 rupees and 12,239 rupees, respectively. Therefore, the cash inputs variable is more accurately a measure of fertilizer use. An appropriate charge on capital use is 10 percent per half-year for Pakistan for most crops. However, the appropriate interest rate on fertilizer use on full-year sugarcane crops would be 20 percent. Consequently, in order to estimate an interest charge appropriate to all crops, including sugarcane, the proportion of fertilizer use on sugarcane acreage to total fertilizer use was calaculated and used to inflate the 10 percent interest charge. The derived interest rate weighted in this manner was 13.5 percent.

Labor. Calculating an average opportunity cost for labor in 1980-81 is highly complicated by the fact that casual labor is hired periodically during critical demand times and paid in both kind and cash; permanent servant labor is hired for either an entire season or the entire year, is paid both in kind and cash, and may consist of full- or part-time adults and/or full- or part-time minors (typically young boys); and own and family labor, also consisting of full- and part-time adults and minors, goes unpaid and must be assigned a shadow price. An average price of casual hired labor was calculated by weighting the average wage per man-day per crop activity by the percentage of total man-days.

The different crop activities for which casual labor was hired included (in order of importance in terms of total man-days), sugarcane cutting and loading (onto bullock carts and tractor trollies), wheat harvesting, fodder harvesting, vegetable hoeing and harvesting, sugarcane spraying, sugarcane hoeing, sugarcane processing, cotton picking, maize hoeing, sugarcane planting, maize harvesting, rice harvesting, rice transplanting, rice plowing, wheat planting and tobacco processing (for local consumption). The average wage for casual hired labor was calculated as 13.84 rupees per man-day for a total of 7,996 man-days.

To calculate the total man-days of permanent servant and family labor, a full-time adult was assigned a full one unit value, part-time adults and full-time minors were assigned a half unit value, and part-time minors were assigned a fourth unit value. Average wages paid to a total of 53.5 permanent servants came to 3,513 rupees per year or 14 rupees per man-day, on the assumption of 250 man-days of active labor input per year per servant (the total man-days in 1980-81 was 13,375). On a similar assumption, the total man-days of family labor in 1980-81 was calculated as 63,625, and the shadow wage of family labor was assumed to be equal to the average wage calculated for permanent servant labor. The weighted average wage rate was then calculated as 14 rupees per man-day.

Bullock power. Since some sampled farmers hired bullocks for, typically, sugarcane hoeing and plowing, the average rental price of approximately five rupees per hour was taken as the opportunity cost of a pair of bullocks.

Tractor power. Only 13 sampled farmers, or 10 percent, owned their own tractor, but all but a very few reported using tractor power for farm operations. The types of field operations included (in order of importance in terms of number of operations), wheat plowing, fodder plowing, sugarcane plowing, fodder planking, maize grain plowing, wheat planking, surarcane planking, maize grain planking, rice plowing, vegetable seedbed preparation, cotton plowing and cotton planking. Tractor power was also very actively used to power mechanical wheat threshers, and occasionally to haul trollies of farm produce to market. The weighted average opportunity cost of tractor power is calculated as 10 rupees per hour.

Comparisons of Marginal Value Products and Opportunity Costs

Computed marginal value products, opportunity costs and ratios of marginal value products to opportunity costs to examine input use efficiencies are presented in Tables V-6 to V-8, below, for sub-samples of: (1) tubewell using and non-tubewell using farms; (2) users of single-family owned and cooperatively- and joint-family owned tubewells; and (3) active and inactive traders. These tables correspond to Tables V-2 to V-4, respectively, of estimated regression coefficients of production functions for these same sub-samples. It will be remembered that these represent some of the important categories of farms discussed in detail above. Table V-6 also presents results on marginal value products and opportunity costs for all sampled farms.

A non-reported marginal value product implies that the estimated production function coefficient for that particular input was not significant within this particular sample at even the 20 percent level. Consequently, the ratio of marginal value product to opportunity cost will also be near (but not equal to) zero, implying a general overuse of this input relative to all other inputs.

Table V-6 indicates that for all sample farms, labor inputs are generally overused; tubewell water, cash inputs and tractor power are underused (actually, since excess capacity likely does not exist with respect to existing tubewells and tractors these inputs are underpriced); and bullock power use is approximately efficient. The implications for canal water use are uncertain from estimated results. The estimated marginal value product for tubewell water picks up all the increased variation in gross income per acre due to water at crucial,

Table V-6. Marginal Value Products, Opportunity Costs and Ratios of MVP to OC of Major per Acre Inputs of Sampled Tubewell Using and Non-tubewell Using Farms, as well as All Farms, 1980-81.

Type of Farm	Sample Size	Input	Unit of measurement	Geometric mean	Marginal value product	Opportunity cost (Rupees)	Ratio of MVP to OC
Tubewell Using	60	Canal Water	Acre Inches	25.57	- *	6.60	-
		Tubewell Water	Acre Inches	17.03	27.61	15.38	1.80
		Cash Inputs	Rupees	381.32	5.49	1.135	4.84
		Labor	Man-Days	75.71	7.66**	14.00	0.55
		Bullock Power	Hours	39.24	- *	5.00	-
		Tractor Power	Hours	2.85	- *	10.00	-
Non-tubewell Using	69	Canal Water	Acre Inches	26.32	- *	6.60	-
		Tubewell Water	Acre Inches	0	0	15.38	0
		Cash Inputs	Rupees	308.59	2.93	1.135	2.58
		Labor	Man-Days	73.84	10.63	14.00	0.76
		Bullock Power	Hours	48.09	6.90	5.00	1.38
		Tractor Power	Hours	2.11	257.50	10.00	25.75
All Farms	129	Canal Water	Acre Inches	25.97	- *	6.60	-
		Tubewell Water	Acre Inches	7.92	20.81	15.38	1.35
		Cash Inputs	Rupees	344.43	3.92	1.135	3.45
		Labor	Man-Days	74.01	11.14	14.00	0.80
		Bullock Power	Hours	43.97	5.25	5.00	1.05
		Tractor Power	Hours	2.43	162.81	10.00	16.28

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a/ Estimated coefficient is insignificant, but different from zero, so MVP cannot be interpreted.

b/ Estimated coefficient is significant at the 20 percent level.

Table V-7. Marginal Value Products, Opportunity Costs and Ratios of MVP to OC of Major per Acre Inputs of Sampled Farms Using Single-Family Owned Tubewells and Cooperatively- and Joint-Family Owned Tubewells, 1980-81.

Type of Farm	Sample Size	Input	Unit of measurement	Geometric mean	Marginal value product	Opportunity cost	Ratio of MVP to OC
Single-Family Owned Tubewell Using	31	Canal Water	Acre Inches	23.59	- *	6.60	-
		Tubewell Water	Acre Inches	20.53	- *	15.38	-
		Cash Inputs	Rupees	357.50	9.33	1.135	8.22
		Labor	Man-Days	83.35	- *	14.00	-
		Bullock Power	Hours	43.08	- *	5.00	-
		Tractor Power	Hours	2.74	- *	10.00	-
Joint-Property Tubewell Using	29	Canal Water	Acre Inches	27.83	- *	6.60	-
		Tubewell Water	Acre Inches	13.03	58.15	15.38	3.78
		Cash Inputs	Rupees	408.54	3.55	1.135	3.13
		Labor	Man-Days	66.56	- *	14.00	-
		Bullock Power	Hours	34.85	- *	5.00	-
		Tractor Power	Hours	3.34	- *	10.00	-

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[a] Estimated coefficient is insignificant, but different from zero, so MVP cannot be interpreted.

Table V-8. Marginal Value Products, Opportunity Costs and Ratios of MVP to OC of Major per Acre Inputs of Sampled Active and Inactive Trading Farms, 1980-81.

Type of Farm	Sample Size	Input	Unit of measurement	Geometric mean	Marginal value product	Opportunity cost	Ratio of MVP to OC
Active Trading	42	Canal Water	Acre Inches	24.53	- *	6.60	-
		Tubewell Water	Acre Inches	11.30	- *	15.38	-
		Cash Inputs	Rupees	350.60	9.39	1.135	8.27
		Labor	Man-Days	73.16	6.80**	14.00	0.49
		Bullock Power	Hours	41.25	- *	5.00	-
		Tractor Power	Hours	2.25	- *	10.00	-
Inactive Trading	71	Canal Water	Acre Inches	26.35	- *	6.60	-
		Tubewell Water	Acre Inches	5.66	- *	15.38	-
		Cash Inputs	Rupees	333.96	3.10	1.135	2.73
		Labor	Man-Days	76.17	10.00	14.00	0.71
		Bullock Power	Hours	46.75	5.87	5.00	1.17
		Tractor Power	Hours	2.46	161.05	10.00	16.11

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[a] Estimated coefficient is insignificant, but different from zero, so MVP cannot be interpreted.

[b] Estimated coefficient is significant at the 20 percent level.

transient peak demand times. However, canal water also contributes to total volumes at these times.

This implies that all farms, in general, would be wise to increase usage of tractor power, in particular, but also cash inputs and (to a lesser degree) tubewell water, wherever possible. An increase in the number of tubewells and tractors per watercourse may be in order. Tubewell water using farms have a very high marginal value product for tubewell water, and could raise net revenues by increasing the use of both tubewell water and cash inputs. Non-tubewell using farms, on the other hand, demonstrate a different shape of production function where net revenues could be increased by added use of tractor power; cash inputs and bullock power.

Table V-7 does not reveal much of interest because of the general tendency for the existence of uninterpretable marginal value products (due to insignificant estimated coefficient values) for both subsamples. However, there is a marked similarity in marginal product values between both single-family tubewell users and common property tubewell users to all tubewell using farms.

Tables V-6 and V-8 demonstrate a remarkable similarity with respect to marginal value product values between tubewell using and active trading farms, on the one hand, and non-tubewell using and inactive trading farms.

These similarities and interrelationships between methods of farmer control are discussed in more detail below.

Interrelationships

Single regression analyses and analysis of variance (ANOVA) were used to further examine the interrelationships between tubewells (tubewell water use), trading and type of internal warabundi discussed at the beginning of this chapter. Regression results are displayed in Table V-9 below. Significant relationships with regard to this particular sample are indicated with respect to all but three estimated equations.

Interpretation of these results is greatly facilitated with the help of a diagram, such as that provided below in Figure V-1. This five-vertex star diagram indicates, along with Table V-9, that the indigenous farmer options of tubewell water use and trading present the strongest alternatives to increasing control over water supplies (production function results represent a better test of this, and results are generally supportive) and gross incomes per acre. The practice of kachha internal warabundi has no apparent direct impact on gross income per acre, as opposed to pakka internal warabundi, yet indirect effects are observable.

Covariance analysis of the previous section tends to support links between each of the three locally-initiated methods of water control taken independently and productivity, while controlling for other inputs. In this section analysis of variance results are used to explore correlations between various means of control and generalized cooperation. At the same time analysis of variance gives information about joint effects of the methods on productivity.

Table V-9. Single Regression Results Relating Tubewell Water Use to Type of Internal Warabundi; Percent of Time Traded to Tubewell Water Use, Type of Tubewell Ownership, Type of Tubewell Power Source, Type of Internal Warabundi and No. of Collective Projects; No. of Collective Projects to Type of Internal Warabundi and Presence of Tubewell; and Gross Income per Acre to No. of Collective Projects.

Eq. No.	Dependent variable	Explanatory variable	Estimated intercept coefficient	Est. slope coeff.	No. of obser-vations	Est. slope coeff. t-ratio	R^2
1	Proportion of tubewell water use per acre to total water use per acre x 100	Dummy: 1=kachha internal warabundi; 0=pakka inter. warabundi	12.02	7.53	129	7.50***	.03
2	% of time traded	Dummy: 1=tubewell water users; 0=non-tubewell water users	5.06	2.83	126	1.33	.01
3	% of time traded	Dummy: 1=users of single-family owned tubewells; 0=users of joint property tubewells	4.15	6.86	57	1.65*	.05
4	% of time traded	Dummy: 1=users of electric-powered tubewells; 0=users of diesel-powered tubewells	9.60	-2.45	57	5.82***	.004
5	% of time traded	Dummy: 1=kachha internal warabundi; 0=pakka internal warabundi	3.69	4.17	128	1.96**	.03
6	% of time traded	No. of collective projects	4.56	1.24	126	1.66*	.02
7	No. of collective projects	Dummy: 1=kachha internal warabundi; 0=pakka internal warabundi	1.06	0.76	129	1.54	.06
8	No. of collective projects	Dummy: 1=tubewell present on watercourse; 0=no tubewell present	1.00	0.83	20	1.20	.07
9	Gross income per acre	No. of collective projects	3113.20	121.47	129	121.00***	.02

Table V-9. Continued.

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*Significance at the 10 percent level.
**Significance at the 5 percent level.
***Significance at the 1 percent level.

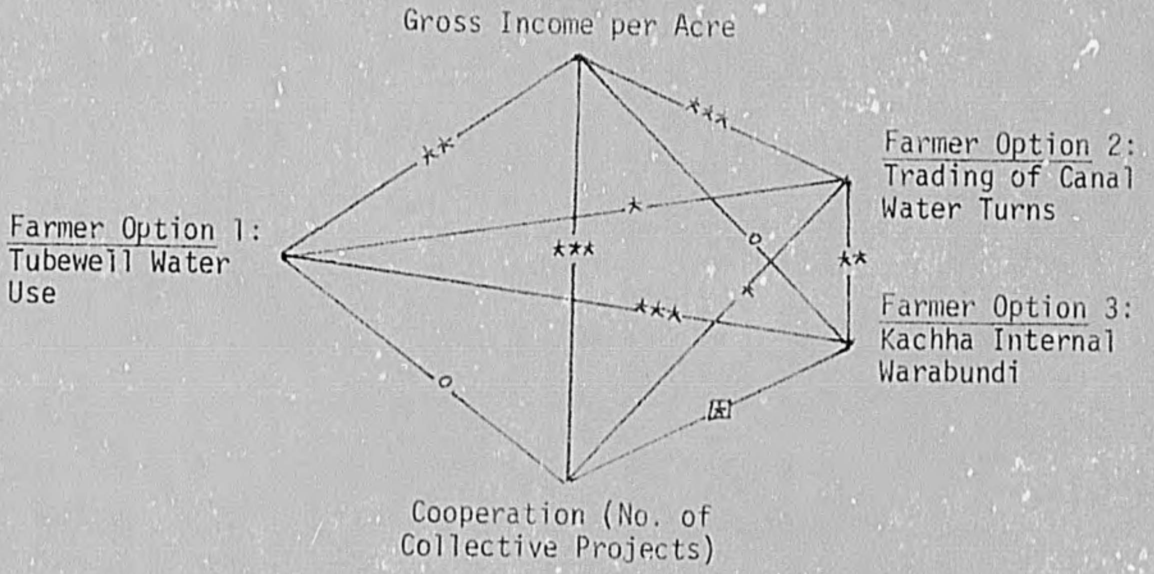

Figure V-1. Levels of Significance between Gross Income per Acre, Cooperation and Three Farmer Options for Increased Control in Water Supplies and Deliveries.

0 = No apparent significant correlation.
$\boxed{*}$ = Significance at the 15 percent level.
* = Significance at the 10 percent level.
** = Significance at the 5 percent level.
*** = Significance at the 1 percent level.

Analysis of variance main, joint and interaction effects are presented in Table V-10. Significance levels are indicated in the extreme right-hand column. Supporting ANOVA tables are presented in Appendix D. It will be noticed from Table V-10 that joint effects and interrelationships are also indicated with regard to watercourse improvement, the subject of Chapter VI. These joint effects and interrelationships will be discussed in that chapter.

There are strong interrelationships indicated between the three indigenous farmer options. Analysis of variance results indicate a strong interaction effect of tubewell use and trading (see Table V-10). There is also a tendency for users of singly-owned tubewell water to be active traders (and vice versa), and for both users of joint property tubewell water and non-tubewell water users to be inactive traders (and vice versa) -- see Appendix D, Table D-2(a). Mean gross income per acre is clearly the highest for active trading, singly-owned tubewell water users than for any other category of trader-cum-tubewell water users.

There is also indication that the practice of kachha internal warabundi is strongly related to both trading and tubewell water use. Regression results in these regards are supported by ANOVA Tables D-2(b) and D-3(a), which show that in this particular sample both active traders and tubewell water users tend strongly to be practicers of kachha internal warabundi. The relatively strong three-way interaction between tubewell water use, active trading and kachha internal warabundi (Table V-10) indicates, for example, that a positive relation exists between per acre gross income and joint use of kachha internal warabundi, trading, and tubewell use. However, for farms practicing

Table V-10. Analysis of Variance Table (Joint, Main and Interaction Effects) Relating Categories of Tubewell Water Use, Trading, Type of Internal Warabundi Practiced, Type of Watercourse and No. of Collective Projects to Gross Income per Acre.

Source of Variation		Sum of Squares	D.F.	Mean Square	F	Sign. of F
Main Effects	Joint Effect	38,252,554	7	5,460,000	3.00	.01
	Tubewell Water Use	15,000,040	2	7,500,000	4.11	.02
	Trading	12,690,293	2	6,340,000	3.48	.04
	Type of Internal Warabundi	246,438	1	246,438	.14	.71
	Type of Watercourse	796,349	1	796,349	.44	.51
	No. of Collective Projects	339	1	339	.00	.99
2-Way Interactions	Joint Effect	46,135,402	19	2,420,000	1.33	.19
	Tubewell Water Use and Trading	19,645,102	4	4,910,000	2.69	.04
	Tubewell Water Use and Type of Internal Warabundi	4,489,624	2	2,240,000	1.23	.30
	Tubewell Water Use and Type of Watercourse	6,277,299	2	3,130,000	1.72	.19
	Tubewell Water Use and No. of Collective Projects	9,563,748	2	4,780,000	2.62	.08
	Trading and Type of Internal Warabundi	918,202	2	459,101	.25	.78
	Trading and Type of Watercourse	2,364,486	2	1,180,000	.65	.53
	Trading and No. of Collective Projects	350,028	2	175,014	.10	.91
	Type of Internal Warabundi and Type of Watercourse	454,101	1	454,101	.25	.62
	Type of Internal Warabundi and No. of Collective Projects	53,362	1	53,362	.03	.87
	Type of Watercourse and No. of Collective Projects	1,588,055	1	1,580,000	.87	.34
3-Way Interactions	Joint Effect	25,398,227	14	1,810,000	1.00	.47
	Tubewell Water, Trading and Type of Internal Warabundi	14,736,565	4	3,680,000	2.02	.10
	Tubewell Water, Trading and Type of Watercourse	408,746	2	204,373	.11	.89
	Tubewell Water, Trading and No. of Collective Projects	6,722,266	2	3,360,000	1.84	.16
	Tubewell Water, Type of Internal Warabundi and Type of Watercourse	3,902,786	1	3,900,000	2.14	.15
	Tubewell Water, Type of Watercourse and No. of Collective Projects	12,247	1	12,247	.01	.94
	Trading, Type of Internal Warabundi and Type of Watercourse	340,573	1	340,573	.19	.67
	Trading, Type of Internal Warabundi and No. of Collective Projects	3,978,973	1	3,970,000	2.18	.14
	Trading, Type of Watercourse and No. of Collective Projects	4,891,904	2	2,440,000	1.34	.27
4-Way Interactions	Tubewell Water, Trading, Type of Internal Warabundi and Type of Watercourse	8,008,687	1	8,000,000	4.43	.04
	Explained	109,780,000	40	2,740,000	1.51	.06
	Residual	160,500,000	88	1,820,000		
	Total	270,290,000	128	2,110,000		

pakka internal warabundi there seems to be little tubewell water use (also see Table D-6(a)).

These results suggest that not only does tubewell water availability lessen the risk of trading (thereby encouraging the incidence and frequency of trading), but kachha internal warabundi also has a positive impact on trading and increases the likelihood of getting tubewell water (on short notice).

Others have suggested that cooperation and conflict among farmers on individual watercourses generalizes to affect farmer ability to cooperate in irrigation related transactions (Merrey, 1979, Mirza and Merrey, 1979). Sparling (1980) has suggested that irrigation water supplies may be a root cause of conflict or cooperation among farms who share a common watercourse. In this study no attempt is made to sort out directions of causality, but data for the 129 farmers is analyzed to identify correlations between methods of seeking water control, productivity and generalized cooperation (on the watercourse level).

Cooperation, as defined by the number of collective projects within recent memory on a watercourse level, was shown in Chapter III to be higher on improved, as opposed to control, watercourses. There is also a strong relationship between sample farmer gross income per acre and the number of collective projects (see Figure V-1). Table D-7 in Appendix D reveals that mean per acre gross income is 8 percent higher on watercourses experiencing a greater than average number of collective projects (two or more), than on watercourses with a less than average number (zero or one).

A strong two-way interaction exists for cooperation and tubewell water use (Table V-10). Relatively less strong three-way interactions are indicated for cooperation, tubewell water use and trading, on the one hand, and cooperation, trading and kachha internal warabundi, on the other.

Furthermore, as revealed in Table D-2(d), many more tubewell water users tend to be found on watercourses with two or more collective projects, and more non-tubewell water users are found on watercourses with zero or one collective project. No general pattern is shown between cooperation and trading (Table D-3(c)). But Table D-4(b) indicates that more kachha internal warabundi arrangements tend to occur on (main) watercourses with more than average cooperation. Three-way interrelationships seem to follow these general patterns: (1) tubewell water use and active trading tend to occur more frequently on more cooperative watercourses (Table D-8(a)); (2) tubewell water use and the practice of kachha internal warabundi tend to occur on more cooperative watercourses (Table D-6(c)); and (3) active trading and kachha internal warabundi also tend to occur on more cooperative watercourses (Table D-8(b)). Not surprisingly, the four-way interaction (Table D-10(b)) indicates that tubewell water users, active traders and kachha internal warabundi practicers tend to occur more frequently on more cooperative watercourses. The class of tubewell water users-cum-traders-cum kachha internal warabundi practicers (n=27) occur on more cooperative watercourses; whereas the class of non-tubewell water users-cum-inactive traders-cum-pakka internal warabundi practicers (n=20) occur on less cooperative watercourses.

Summary

Results from this chapter suggest that all locally-initiated measures of control positively affect productivity, with strongest effects shown by (1) tubewell water use, and (2) active trading of canal water. There are also strong joint effects demonstrated between the measures, notably the two-way interaction between tubewell water use and trading, and the three-way interaction between all indigenous methods. These interaction effects indicate both mutually supportive activities, as well as a larger, synergistic impact on productivity.

Having examined in detail the effects of the locally-initiated methods of control over water supplies and productivity, and the key interrelationships between the methods, we are in a position to investigate the relative impacts of watercourse improvement (an extraneous project) on both flexibility and productivity. Watercourse improvement also represents another method to secure control because it theoretically increases year-round water supplies on the watercourse by decreasing conveyance losses.

CHAPTER VI

OFWM WATERCOURSE IMPROVEMENT EVALUATION

In Chapter V the effects of three indigenous methods used by Pakistani farmers to increase the flexibility of water supplies were analyzed. In this chapter we consider another method which, in principle, directly and indirectly affects flexibility: watercourse improvement.

By reducing conveyance losses, watercourse improvement increases overall supplies of canal water, with proportionately greatest gains going to tail-end farmers who are most affected by conveyance losses. The overall increase in canal water supply acts to reduce the urgency of need for a flexible supply; and because it reduces the urgency of short-term demand, it tends to increase the willingness of neighbors to relinquish a partial turn.

The watercourse improvement program is treated separately from the other methods of increasing control because it is typically not initiated from within the watercourse command and because it is the subject of considerable government expenditure.

The methods used to analyze its effects are similar to those used for the other methods. It should be remembered, however, that interpretation of the great majority of statistical values derived and significance levels apply only to this particular sample and not to a larger population, due to the non-randomness of the sampling procedure.

Comparisons of farms on watercourses improved in 1977-78 and 1978-80 will enable tests of any crop-related differences in "older" (those three to four years old at the time of the survey) and "newer" (those only one to two years old) improved watercourses. Here, it is hypothesized that the "older" improved watercourses will account for stronger positive impacts on crop production than "newer" ones, as farmers make adjustments, over time, in cropping patterns, cropping intensities and other related input use in response to continued higher conveyance efficiencies and increased year-round water supplies (in relation to conveyance efficiencies and water supplies received before watercourse improvement).

Comparisons will also be made between sampled farms at head-, middle- and tail-relative watercourse command locations, in order to examine the effects of watercourse improvement on downstream irrigation. In particular, it is hypothesized that watercourse improvement will have its most profound effects on tail-enders.

Prior to discussion of these major crop- and income-related results, however, the hypothesis that watercourse improvement does, in fact, result in significantly decreased conveyance losses, and improved conveyance efficiencies, can be examined. Significance levels and tests are directly interpretable here because the improved watercourses were selected through random sampling procedures.

Watercourse Conveyance Losses and Efficiencies

Perhaps the major expressed objective of the OFWM watercourse improvement project is to decrease seepage and conveyance losses in the main watercourses.

This objective was due in large part to the research efforts of the Colorado State University (CSU) field team staff in Pakistan and the Master Planning and Review Division of the Pakistan Water and Power Development Authority (WAPDA). Estimates of the percent of canal water lost through seepage and evaporation in transit during a typical warabundi rotation period ranged from 30 percent to 57 percent (see for example, WAPDA, 1979; Trout and Bowers, 1979; Lowdermilk, et al., 1978; and Gibb, et al., 1966). An average 50 percent conveyance efficiency was generally agreed upon for policy proposals and planning (Clyma, et al., 1981). Trout and Bowers (1979) also demonstrated, in this regard, that over 80 percent of overall measured conveyance losses were the result of steady-state seepage and leakage into the banks of water channels.

A direct test of the effectiveness of OFWM watercourse improvement is a comparison of conveyance efficiencies for improved and control watercourses. Canal water flow estimates based on flume measurements of the observed watercourses enabled this test to be made. Average loss rate functions and loss rates per thousand feet were subsequently estimated. Tests of form revealed that linear loss rate functions approximated the data as well as or better than quadratic or polynomial functions (confirming the findings of Trout and Bowers, 1979). These loss rate functions, as well as details of flume volume measurements and percentage per thousand feet loss rates, are reported in Table VI-1, below.

Table VI-1 reveals that the thousand feet loss rate functions from head to tail had to be approximated for four improved and three control watercourses due to a lack of tail measurements (see column 8). There

Table VI-1. Measured Flows, Percentage Losses and Estimated Loss Rate Functions on Improved and Unimproved (Control) Watercourses. (Note: 1 cusec hour = 1.032 acre inch hours)

(1) Type of w/c and no. of w/c (moga)	(2) Measured head (moga) discharge (Acre Inch Hours)	(3) Measured middle flow (A.I. Hrs.)	(4) Distance (feet) from head to middle flume	(5) % loss from head ($\frac{2-3}{3}$x100)	(6) % loss from head per thous.ft. (5÷4)	(7) Loss rate function head to middle per thous.ft.	(8) Measured tail flow (A.I. Hrs.)	(9) Distance (feet) from middle to tail flume	(10) % loss from middle ($\frac{3-8}{8}$x100)	(11) % loss from middle per thous.ft. (10÷9)	(12) Loss rate function, middle to tail per thous.ft.	(13) Distance (feet) from head to tail flume	(14) % loss from head to tail ($\frac{2-8}{8}$x100)	(15) % loss from head to tail per thous.ft. (14÷13)	(16) Per acre loss rate function, head to tail per thous.ft.
IMPROVED															
1	1.50						1.24					7,040	21	3.0	Y=.04x
2	2.17						1.75					5,940	24	4.0	Y=.07x
3	1.14														$Y=.04x^{b/}$
4	0.88														$Y=.04x^{b/}$
5	2.27														$Y=.05x^{b/}$
6	1.17	1.14	2,200	3	1.4	Y=.01x					$Y=.04x^{b/}$				$Y=.02x^{b/}$
7	1.86						1.41					4,400	32	7.3	Y=.04x
8	1.44						1.14					7,700	26	3.4	Y=.04x
9	2.48						1.86					8,580	33	3.8	Y=.07x
10	0.88						0.83					3,960	6	1.5	Y=.01x
Average Improved Watercourses													24	3.8	Y=.04x
UMIMPROVED															
11	2.68	1) 2.58 2) 1.86	1) 4,400 9,460	1) 4 31	1) .9 3.3	Y=.02x Y=.05x	1.75	1) 10,120 2) 5,060	1) 47 6	1) 4.6 1.2	Y=.04x	14,520	53	3.6	$Y=.07x^{b/}$
12	2.53	2.22	5,720	12	2.1	Y=.08x	1.75	1,980	27	18.6	Y=.23x	7,700	45	5.9	$Y=.10x^{b/}$
13	1.24						1.08					3,520	15	4.3	$Y=.04x^{b/}$
14	0.72	0.57	1,110	21	19.0	Y=.14x	0.52	3,300	10	3.0	Y=.06x	4,400	38	8.6	$Y=.09x^{b/}$
15	1.34						1.14					9,460	18	1.9	$Y=.02x^{b/}$
16	1.90	1.55	8,800	18	2.0	Y=.04x	1.24	5,500	25	4.5	Y=.05x	14,300	53	3.7	$Y=.05x^{b/}$
17	1.44					$Y=.23+.05x^{a/}$					$Y=.36+.05x^{a/}$				$Y=.06x^{b/}$
18	1.70	1.70	2,420	0	0.0		1.24	3,520	37	10.5	Y=.13x	5,940	37	6.2	$Y=.08x^{b/}$
19	1.03					$Y=.23+.05x^{a/}$					$Y=.36+.05x^{a/}$				$Y=.06x^{b/}$
20	1.39					$Y=.23+.05x^{a/}$					$Y=.36+.05x^{a/}$				$Y=.06x^{b/}$
Average Unimproved Watercourses				14	4.6	$Y=.23+.05x^{a/}$			25	6.2	$Y=.36+.05x^{a/}$		37	4.9	$Y=.06x^{b/}$

a/ Regression equation estimation
b/ Simple average

was only one middle measurement taken on one improved watercourse (column 3), which prevented the estimation of head to middle and middle to tail loss rate functions on improved watercourses. However, six middle measurements were taken on control watercourses which enabled the estimation of head to middle and middle to tail loss rate functions using simple linear regression techniques. The estimated average thousand feet loss rate functions for control watercourses are reported below:

$$Y_{(H-M)} = .23 + \underset{(2.33)^{*}}{.05}X_{(H-M)} \qquad (VI.1)$$

$$r^2 = .52 \quad n = 7 \quad F = 5.41^{*}$$

$$Y_{(M-T)} = .36 + \underset{(1.47)}{.05}X_{(M-T)} \qquad (VI.2)$$

$$r^2 = .35 \quad n = 7 \quad F = 2.15$$

where Y = volume of canal water loss per thousand feet in acre inches, X = distance in thousand feet from the nearest upstream flume measurement, (H-M) = head to middle, (M-T) = middle to tail, and * = significance at the 10 percent level.

Percentage losses from head to tail per thousand feet (column 15) are higher on control watercourses, but it must be remembered that these figures do not reflect total (main) watercourse losses in an average week or warabundi rotation. They are, instead, average per thousand feet losses during the time when the main watercourse channel (<u>not</u> including the branches) was full at the end of the rotation, and only reflect differences in supplies typically received at head and tail per hour of warabundi time or turn. In fact, the average per thousand feet loss rates, as reflected in column 16, for both types of watercourses, do not demonstrate any significant difference at the 10 percent level using the t-test for differences in mean values.

While these results are discouraging, the lack of tail measurements on seven watercourses and the inability to measure total losses in a given warabundi rotation detract from conclusions drawn from Table VI-1. Canal water use per acre is, in fact, considerably higher (18 percent) on improved watercourses (see Table VI-2). These findings are supported by simple linear regression results for this particular sample (presented in Equation VI.3), demonstrating that farms on improved watercourses receive and apply an average of 4.28 acre inches, or 18 percent, more canal water per acre (given approximately equivalent canal outlet discharges) than farms on control watercourses.

$$\text{Canal Water Use per Acre} = 23.81 + \underset{(2.70)^{***}}{4.28D} \qquad \text{(VI.3)}$$

$$r^2 = .05 \qquad n = 129 \qquad F = 7.313^{***}$$

(D: 1 = improved watercourse; 0 = control watercourse)

A measure of quality of watercourse cleaning and maintenance

Another way devised to examine the relative quality of sampled watercourses in conveying canal water was a scoring system (as described in Chapter III), based on assigning penalty points on the basis of observed silting of head sections; actual counts of cracked or broken concrete structures (on improved watercourses only); illegal nakkas and trees; and observed frequencies of weak or broken banks, rat holes and vegetation at head, middle and tail locations on the main watercourses, including branches. According to this method the lower the score the better the quality of the watercourse. Results using this method, however, are inconclusive. Inter-coder reliability tests could not be done to evaluate the scoring system. Such tests would examine whether the sampled watercourse qualities would have been consistently scored the same by different coders.

Also, construction of a 95 percent confidence interval using t-ratios to test for differences in mean values of overall quality scores on the two types of watercourses indicates that there are significant differences between the two: the mean overall score for improved watercourses is 14.6, and for unimproved watercourses is 23.2; the 95 percent confidence interval is 8.6±3.6. Analyses on the six separate components of this overall score reveal that there are <u>no</u> significant improvements in silting of head sections, presence of weak or broken banks, or presence of rat holes after watercourse improvement. But there are significant improvements with regard to number of illegal nakkas, degree of vegetation and number of trees.

Unfortunately, however, the reliability of this scoring system is brought into doubt when simple regression analysis is used to test the relationship between the overall quality score (the regressor) and measured volumes of canal water lost per acre (in acre inches – the dependent variable), for all watercourses:

$$\text{Volume Lost/Acre} = .006 + \underset{(.06)}{.0003}\ (\text{Watercourse Quality Score}) \qquad \text{(VI.4)}$$

$$r^2 = .08 \qquad n = 20 \qquad F = .004$$

From this simple estimation we see that the quality score coefficient value is insignificant at any level.

Based upon these various analyses, it appears that the OFWM watercourse improvement project is decreasing losses in watercourses and improving conveyance efficiencies, but not by the magnitude indicated from earlier studies. In fact, the observed conveyance losses on improved watercourses are not decidedly lower than those on control watercourses. Average head-to-tail conveyance efficiencies on six improved watercourses are 81 percent, versus 74 percent on seven control watercourses. The percentage difference (improvement) is only 9 percent.

Cropping Intensities and Cropping Patterns

Before analyzing the economic returns to watercourse improvement, it is interesting to examine whether cropping intensities are higher and cropping patterns different on different categories of farms and watercourses. Table VI-2, below, summarizes much of the data on means, standard deviations and percentage differences in contrasted sub-sample means with respect to both cropping intensities and cropping patterns, as well as per acre gross incomes and main crop production-related inputs. (This table is similar to Table V-1, above, with respect to sub-categories of indigenous farmer control enhancing options.)

It is interesting that cropping intensities and cropping patterns (as measured by the percent of high water-using crops grown) are essentially the same on all watercourses and on all types of farms. No strong difference is demonstrated on improved versus control watercourses, or "older" watercourses improved in 1977 and 1978 versus "newer" watercourses improved in 1979 and 1980.

Table VI-2. Sample Sizes, Mean Values, Percentage Differences in Contrasted Sub-sample Mean Values and Standard Deviations for Sub-samples of Farms on Improved and Control (Unimproved) Watercourses, Watercourses Improved from 1977 to 1980, and Head, Middle and Tail Watercourse Positions.

		Gross Income per acre			Canal Water Use per acre			Tubewell Water Use per acre			Cash Input Expend. per acre			Labor Use per acre			Bullock Power per acre			Tractor Power per acre			Cropping Intensity			% of High Water Using Crops Grown		
Sub-sample category	No. of obser-vations	Mean (Rs.)	% diff. in means	Std. dev.	Mean (ac.in.)	% diff. in means	Std. dev.	Mean (ac.in.)	% diff. in means	Std. dev.	Mean (Rs.)	% diff. in means	Std. dev.	Mean (mandays)	% diff. in means	Std. dev.	Mean (hrs.)	% diff. in means	Std. dev.	Mean (hrs.)	% diff. in means	Std. dev.	Mean (%)	% diff. in means	Std. dev.	Mean (%)	% diff. in means	Std. dev.
Improved Watercourses	65	3482	12	1499	28.1	18**	8.9	11.6	180**	18.4	369	15*	171	77.4	10	40.1	41.7	-11	23.5	2.7	22	1.9	165	0	28	37	8	21
Control Watercourses	64	3108		1391	23.8		9.1	4.2		8.7	320		139	70.6		34.3	46.3		17.4	2.2		1.9	164		25	34		18
1977-78 Improved Watercourses	38	3679	15	1415	27.9	-2	8.8	7.3	-142**	9.6	369	0	157	76.3	-4	40.3	42.2	3	20.8	2.6	-10	1.9	167	4	25	36	-9	16
1979-80 Improved Watercourses	27	3205		1596	28.4		9.1	17.7		25.3	369		193	78.9		40.6	40.9		27.3	2.8		1.9	161		32	39		27
Head Farms	47	3731	13 36***	1600	28.3	11 19**	9.3	9.7	10 111*	19.2	386	11 33***	182	76.3	-5 19*	34.8	45.2	10 -2	24.1	2.7	7 47**	2.3	173	6 11**	25	39	13 19**	23
Middle Farms	44	3305	20	1503	25.4	7	8.4	8.8	92	14.3	346	19	135	80.1	25	46.5	41.1	-12	22.3	2.6	37	1.8	163	4	26	35	5	18
Tail Farms	38	2750		975	23.7		9.6	4.6		7.3	291		137	64.1		25.7	45.9		13.2	1.9		1.3	156		25	33		15
Head Farms Improved W/C's	25	4332	42***	1753	30.5	18*	10.5	15.7	423**	23.1	443	38**	214	76.8	1	41.1	42.6	-13	27.5	2.7	0	2.2	179	8*	28	46	48**	24
Head Farms Control W/C's	22	3048		1084	25.8		7.3	3.0		10.4	321		108	75.7		27.0	48.1		19.8	2.7		2.5	166		21	31		20
Middle Farms Improved W/C's	21	3129	-11	1083	28.6	22**	7.2	11.2	70	18.5	365	11	105	85.3	13	48.1	33.7	-12	25.5	2.9	26	1.9	158	-6	24	34	-3	17
Middle Farms Control W/C's	23	3467		1815	23.4		7.3	6.6		8.8	329		158	75.4		45.4	43.2		19.2	2.3		1.7	167		28	35		19
Tail Farms Improved W/C's	19	2755	0	939	24.4	6	7.3	6.7	168*	8.2	275	-12	119	69.3	18	27.5	43.7	-10	14.7	2.3	64**	1.5	153	-4	26	29	-28*	16
Tail Farms Control W/C's	13	2744		1035	23.0		11.5	2.5		5.8	307		154	58.9		23.3	48.0		11.4	1.4		0.9	159		25	37		13

There are, however, substantial differences in all head versus all tail farmers in cropping intensities and percent of high water-using crops grown. There are also meaningful differences in both mean cropping intensities and cropping patterns between head farmers on improved watercourses versus control watercourses. Surprisingly, tail farmers on control watercourses grow an average of 28 percent more high water-using crops in 1980-81 than tail farmers on improved watercourses.

Crop Yields and Overall Crop Production

We have seen that the primary objective of the watercourse improvement project is to reduce conveyance losses in the main watercourse and improve conveyance efficiencies from the canal outlets to the nakka outlets throughout the main watercourse length. Results of this research are inconclusive: some tests indicate that some improvements are being made in this regard by OFWM, but others indicate the opposite effect. Whether or not there are substantial improvements in conveyance efficiencies is not clear cut, and, at any rate, is something of an academic exercise for the purposes of this dissertation, since any improvements only represent potential benefits. Increased productivity must be the major test of results.

The production function model used to test the hypothesis that factor/output relationships on improved watercourses are different from those on control watercourses, and that these relationships differ between head, middle and tail farms is of the same form as that used in Chapter V, with changes in the types of farms (i). For the purposes of this chapter, i = 9: namely, 1 = farms on improved watercourses; 2 = farms on control (unimproved watercourses); 3 = farms on watercourses improved in 1977; 4 = farms on watercourses improved in 1978; 5 = farms on watercourses improved in 1979; 6 = farms on watercourses improved in 1980; 7 = head position farms; 8 = middle position farms; and 9 = tail position farms.

Production function results with respect to farms on improved and control watercourses, and all farms, are presented in Table VI-3, below.

Covariance tests on differences in production functions (slope vectors) between the improved and control watercourses indicate no strong difference. Moreover, the estimated variance of the error term (error sum of squares/[n-7]) is nearly the same for both regressions, giving no evidence of increased farmer control over per acre production.

Comparisons of mean and standard deviation values, presented in Table VI-2, above, reveal that mean gross income per acre is only 12 percent higher on improved watercourses, not a statistically significant difference. This result is apparently not biased by the aggregation of all crops into a single value of total production figure, since separate t-tests also do not reveal overwhelming differences in yields of major crops on the two types of watercourses (see Table VI-4, below).

Comparisons of differences in mean per acre input usage (Table VI-2, above) between improved and control watercourses, show significant differences only for canal water and cash inputs, both at the 90 percent confidence level. Tubewell water use is a remarkable 180 percent higher on improved watercourses, yet a t-test applicable to this

Table VI-3. Regression Coefficients Relating Logarithms of Gross Value of Production per Acre to Logarithms of Various Inputs for a Sample of Irrigated Farms on Improved, Control and All Watercourses, 1980-81 (Cobb-Douglas Model).

Explanatory variable	Unit	Farms on improved watercourses	Farms on all watercourses	Farms on control watercourses
Canal Water per Acre	Acre Inches	.28 (1.70)*	-.01 (.18)	-.09 (.91)
Tubewell Water per Acre	Acre Inches	.07 (1.96)**	.05 (1.78)**	.04 (.92)
Cash Inputs per Acre	Rupees	.39 (3.40)***	.41 (5.27)***	.42 (3.82)***
Labor per Acre	Man Days	.19 (1.95)**	.25 (3.53)***	.33 (2.95)***
Bullock Power per Acre	Hours	.11 (2.86)***	.07 (2.27)**	.05 (.80)
Tractor Power per Acre	Hours	.20 (2.29)**	.12 (2.08)**	.06 (.76)
Intercept		3.48	4.28	4.24
R^2		.41	.35	.35
Overall F-Statistic		6.61*	11.07**	5.05**
Error Sum of Squares/ (n-7)		.13	.14	.14
Covariance Test F-Statistic			0.94	
Sample Size (n)		65	129	64
Sum of Non-intercept Coefficients		1.24	.89	.81

(Numbers in parentheses represent t-ratios.)
*Significance at the 10 percent level.
**Significance at the 5 percent level.
***Significance at the 1 percent level.

Table VI-4. Mean Yields (in maunds per acre) for Major Crops Grown on a Sample of Irrigated Farms on Improved and Control Watercourses, with Percentage Differences and t-test Confidence Intervals, 1980-81.

Crop	No. of observations	Improved watercourses	Control watercourses	% diff.	90% t-test confidence intervals
Sugarcane	69	419	346	21	70±58
Wheat	126	30	27	11	3±3
Kharif Fodder	120	289	263	10	26±27
Rabi Fodder	105	773	689	12	84±81
Maize Grain	70	20	14	43	6±4

particular sample indicates no significant difference between the two types of watercourses, because of the high variations present.

The Effects of Watercourse Improvement Over Time

There is reason to expect that benefits from watercourse improvement are a function of time. That is, if farmers are realizing improved conveyance efficiencies, it can be expected that they will gradually realize higher per acre yields and gross incomes as improvements in field application efficiencies also occur. Furthermore, it takes time for farmers to adjust cropping patterns and intensities to improvements in conveyance efficiencies. We may therefore hypothesize that yields and gross incomes will continue to increase for some time after watercourse improvement and that production functions estimated for recently improved watercourses will differ from those estimated for improved watercourses on which farmers had more time to adjust.

To test this hypothesis watercourses improved in the four year, eight season period from 1977-80 were sampled. Regression analyses showed that there were no major differences in gross incomes per acre between watercourses improved in 1977 or 1978, or between 1979 and 1980, although differences were demonstrated between 1977 and 1979/80, and 1978 and 1979/80. In order to conserve on degrees of freedom for more accurate and powerful testing, therefore, observations from watercourses improved in 1977 and 1978 were aggregated, as were observations from watercourses improved in 1979 and 1980. Production function results are summarized in Table VI-5, below.

Covariance tests on differences in production functions indicate no difference of great magnitude. The fact that the sums of

Table VI-5. Regression Coefficients Relating Logarithms of Gross Value of Production per Acre to Logarithms of Various Inputs for a Sample of Irrigated Farms on Improved Watercourses, 1980-81 (Cobb-Douglas Model).

Explanatory variable	Farms on 1977/78 improved watercourses	All farms on improved watercourses	Farms on 1979/80 improved watercourses
Canal Water per Acre	.24 (1.19)	.28 (1.70)*	.54 (1.95)
Tubewell Water per Acre	.08 (1.42)	.07 (1.96)**	.11 (1.81)
Cash Inputs per Acre	.45 (2.87)***	.39 (3.40)***	.31 (1.70)
Labor per Acre	.17 (1.38)	.19 (1.95)**	.24 (1.34)
Bullock Power per Acre	.08 (1.29)	.11 (2.86)***	.10 (1.88)
Tractor Power per Acre	.06 (.39)	.20 (2.29)**	.32 (2.42)**
Intercept	3.67	3.48	2.57
R^2	.40	.41	.54
Overall F-Statistic	3.42*	6.61**	3.93*
Error Sum of Squares/ (n-7)	.10	.13	.16
Covariance Test F-Statistic		1.44	
Sample Size (n)	38	65	27
Sum of Non-intercept Coefficients	1.08	1.24	1.62

(Numbers in parentheses represent t-ratios.)
*Significance at the 10 percent level.
**Significance at the 5 percent level.
***Significance at the 1 percent level.

non-intercept coefficients are significantly greater than one in all three sample cases in Table VI-5 indicates increasing returns to scale in all models.

Referring back to Table VI-2, it is seen that differences of mean gross income per acre for the two groups are not significant at the 90 percent level. The lack of significant difference in productivities is somewhat puzzling in view of statistically significant, higher mean tubewell usage for the 1979/80 improved watercourses. Returning back to Table VI-5, it is seen, that the estimated variance of the error term (error sum of squares/[n-7]) is appreciably higher for the recently improved watercourse sample. This, in combination with the greater tubewell use within the same sample, indicates that comparisons may be confounded by unanticipated differences between the two subsamples.

Consequently, our tentative hypothesis is not confirmed that age of improved watercourses is an important factor in determining per acre gross incomes. But, in order to fully evaluate the hypothesis that older improved watercourses are yielding substantially more benefits than newer improved watercourses, we also need to demonstrate that 1977/78 improved watercourses influence per acre gross incomes and cropping intensities more than control watercourses.

Regression results indicate that the year of watercourse improvement does not noticeably affect either gross incomes per acre or cropping intensities. Equations VI.5 and VI.6, below, demonstrate through the use of a 1977/78 improved watercourse dummy, D_1, and a 1979/80 improved watercourse dummy, D_2, that neither gross incomes per acre nor cropping intensities are greatly affected by watercourse improvement, regardless of the year of improvement.

$$\ln GIA = 4.35 + \underset{(1.16)}{.09D_1} - \underset{(1.43)}{.14D_2} - \underset{(.47)}{.04 \ln CWA} + \underset{(1.57)}{.05 \ln TWA} \qquad (VI.5)$$

$$+ \underset{(4.85)^{***}}{.40 \ln CIA} + \underset{(3.46)^{***}}{.27 \ln LBA} + \underset{(1.72)^{*}}{.05 \ln BHA} + \underset{(1.95)^{**}}{.10 \ln TRA}$$

$$R^2 = .37 \qquad n = 102 \qquad F = 7.99^{***}$$

$$CRI = 164.36 + \underset{(.52)}{2.67D_1} - \underset{(.53)}{3.25D_2} \qquad (VI.6)$$

$$R^2 = .003 \qquad n = 129 \qquad F = .28$$

Therefore, it appears that whereas older improved watercourses are tending to deliver relatively higher gross incomes per acre than newer improved watercourses (after a period of adjustment to any improvements realized in conveyance efficiencies), watercourse improvement, irregardless of the year of improvement or duration since watercourse improvement occurred, is still not accounting for large crop-value-related benefits in comparisons between improved and control watercourses.

The Effects of Watercourse Improvement on Tail Reaches

Another hypothesis of this study is that benefits of watercourse improvement are skewed in favor of tail farms of watercourse commands. This is because watercourse improvement is designed to substantially improve the conveyance efficiencies of middle and tail reaches, yet it will leave head reaches virtually unchanged. In particular, we would like to test whether tail farms on improved watercourses are receiving sizably more benefits than tail farms on control watercourses. For close comparison, a minimum of two tail farms were sampled on all watercourses, wherever possible, including the "last" irrigator in the warabundi rotation.

Analyses of mean values, presented in Table VI-1, reveals that although per acre gross incomes are an average of 42 percent higher for head farms on improved watercourses, they are lower by an average of 11 percent for middle farms and, more importantly, the mean per acre gross incomes are equal on tail farms. The large difference in head farms with respect to type of watercourse is no doubt due in large part to the 423 percent higher use of tubewell water per acre on improved watercourses, and 60 percent higher use of all water per acre.

Since the hypothesis that tail farms are benefiting substantially more on improved watercourses than on control watercourses is not substantiated in this sample, another model was devised to test whether there were any significant differences between head, middle and tail farmers overall. Table VI-6, below, presents the regression results of a production function model distinguishing between the three relative watercourse positions, irrespective of type of watercourse.

Covariance tests on differences in production function slope vectors between head and tail farms indicate major differences. The most striking difference is between tail farms and all other farms where the estimated per acre canal water coefficient is negative and significant. This implies that among farms at the tail of the watercourse, those using relatively more canal water per acre in relation to other tail farms (i.e., more than the mean of 4.6 acre inches) are realizing noticeably lower gross incomes per acre.

Table VI-6. Regression Coefficients Relating Logarithms of Gross Value of Production per Acre to Logarithms of Various Inputs for a Sample of Irrigated Farms with Respect to Relative Watercourse Position, 1980-81 (Cobb-Douglas Model).

Explanatory variable	All farms	Head farms	Middle farms	Tail farms
Canal Water per Acre	-.01 (.18)	.09 (.50)	.09 (.73)	-.32 (2.22)**
Tubewell Water per Acre	.05 (1.78)**	.11 (2.50)**	.02 (.48)	.01 (.23)
Cash Inputs per Acre	.41 (5.27)***	.40 (2.71)***	.31 (2.22)**	.32 (2.53)**
Labor per Acre	.25 *** (3.53)	.22 (1.63)*	.24 (2.26)**	.32 (2.10)**
Bullock Power per Acre	.07 (2.27)**	.10 (2.30)**	.05 (.76)	.13 (1.59)
Tractor Power per Acre	.12 (2.08)**	.17 (1.82)*	.14 (1.00)	.02 (.23)
Intercept	4.28	3.95	4.61	5.21
R^2	.35	.44	.34	.42
Overall F-Statistic	11.07***	5.29**	3.19*	3.86*
Error Sum of Squares/ (n-7)	.14	.15	.14	.10
Covariance Test F-Statistic	2.50**			
Sample Size (n)	129	47	44	38
Sum of Non-intercept Coefficients	.89	1.09	.85	.48

(Numbers in parentheses represent t-ratios.)
*Significance at the 10 percent level.
**Significance at the 5 percent level.
***Significance at the 1 percent level.

This rather curious phenomenon is explained, in part, by differences within the sample of tail farmers; that is, differences between "last" irrigators and other tail farmers. It will be recalled that the stratified sampling technique used in this research called for two tail farmers to be interviewed on each watercourse, and, wherever possible, for one of these tail farmers to be the "last" irrigator -- i.e., the one receiving the last scheduled warabundi turn. It was hypothesized that because "last" irrigators typically receive the largest allocation of nikal (or emptying the watercourse) time, they would, in fact receive more canal water per acre than other tail farmers. This is apparently true as demonstrated in Table VI-7, below.

Last irrigators use an average of 7 percent more canal water per acre than other tail farmers (although the t-test shows no significant difference in mean values, even at the 80 percent level). However, last irrigators also realize an average of 16 percent less gross income per acre than other tail farmers. It is probable that last irrigators' lands tend to be waterlogged, implying being in Stage III of production. This would be consistent with the negative and significant canal water coefficient in Table VI-6. Waterlogging may be largely due to last irrigators being forced to receive periodic unwanted supplies from upstream irrigators. It was observed in Chapter IV that many main watercourses could be slightly extended to an adjoining open tributary drain to dispose of excess, unwanted canal water supplies.

Efficiency of Production Function Input Use

The computational results of marginal value products, opportunity costs, efficiency of input use ratios and two-tailed t-test-statistics

Table VI-7. Gross Income per Acre and Canal Water Use per Acre Means, Standard Deviations, Percentage Differences in Means and t-test Confidence Intervals for Mean Differences in a Sample of "Last" Irrigators and Other Tail Farmers, 1980-81.

Type of farmer	No. of observations	Gross Income per Acre				Canal Water Use per Acre			
		Mean	Std. dev.	% diff. in means	t-test 80% conf. int.	Mean	Std. dev.	% diff. in means	t-test 80% conf. int.
"Last" Irrigators	14	2494	908	-16	391±422	24.7	13.3	7	1.6±4.4
Other Tail	24	2885	1020			23.1	6.7		

are presented in Tables VI-8 and VI-9, below, for improved and control watercourses, and head, middle and tail farms. Table VI-8 reveals that for farms on improved watercourses, the tractor power input has the highest ratio between MVP and opportunity cost, followed by canal water, cash inputs, bullock power, tubewell water and labor, in descending order. Profits can apparently be increased with additional use of all inputs except labor until MVP equals opportunity cost.

Table VI-9 indicates that it is unknown whether canal water is being efficiently used on head and middle farms (MVP's for these farms cannot be computed from insignificant estimated coefficient values), but is highly overutilized on tail farms. Also, profits can be substantially increased by added use of tubewell water on head farms, but middle and tail farms would benefit from decreased use of tubewell water.

The Relation of Watercourse Improvement to Canal Water Trading and Cooperation

It was earlier hypothesized that with decreases in conveyance losses, canal water trading would be encouraged on improved watercourses among more farmers and over longer distances. If this is, in fact, so, then it was also inferred that this would signify increased crop production and incomes. However, since no sizable difference in per acre gross incomes was demonstrated between improved and control watercourses, the suggestion is that trading could not be expected to be noticeably higher on improved watercourses.

One test of this hypothesis using regression techniques does not reveal a large correlation between our earlier measure of trading, per-

Table VI-8. Marginal Value Products, Opportunity Costs and Efficiency of Input Use Ratios $(\frac{MVP}{O.C.})$ of Major per Acre Inputs of Sampled Farms on Improved and Control Watercourses, 1980-81.

Type of watercourse	No. of observations	Input	Unit of measurement	Geometric mean	Marginal value product	Opportunity cost (Rupees)	Ratio of MVP to O.C.
Improved	65	Canal Water	Acre Inches	28.10	34.70	6.60	5.26
		Tubewell Water	Acre Inches	11.63	20.96	15.38	1.36
		Cash Inputs	Rupees	368.92	3.68	1.135	3.24
		Labor	Man-Days	77.37	8.55	14.00	0.62
		Bullock Power	Hours	41.66	9.20	5.00	1.84
		Tractor Power	Hours	2.66	261.83	10.00	26.18
Control	64	Canal Water	Acre Inches	23.81	- [a]	6.60	-
		Tubewell Water	Acre Inches	4.16	- [a]	15.38	-
		Cash Inputs	Rupees	319.56	4.09	1.135	3.60
		Labor	Man-Days	70.60	11.53	14.00	1.04
		Bullock Power	Hours	46.32	- [a]	5.00	-
		Tractor Power	Hours	2.18	- [a]	10.00	-

[a] Estimated coefficient is insignificant, but different from zero, so MVP cannot be interpreted.

Table VI-9. Marginal Value Products, Opportunity Costs and Efficiency of Input Use Ratios ($\frac{MVP}{O.C.}$) of Major per Acre Inputs of Sampled Farms at Head, Middle and Tail Relative Positions on Sampled Watercourses.

Relative position on watercourse	No. of observations	Input	Unit of measurement	Geometric mean	Marginal value product	Opportunity cost (Rupees)	Ratio of MVP to O.C.
Head	47	Canal Water	Acre Inches	28.29	- a/	8.00	-
		Tubewell Water	Acre Inches	9.74	42.14	10.08	4.18
		Cash Inputs	Rupees	385.92	3.87	1.135	3.14
		Labor	Man-Days	76.32	10.76	14.00	0.77
		Bullock Power	Hours	45.15	8.26	5.00	1.65
		Tractor Power	Hours	2.74	231.50	10.00	23.15
Middle	44	Canal Water	Acre Inches	25.44	- a/	8.00	-
		Tubewell Water	Acre Inches	8.84	- a/	12.37	-
		Cash Inputs	Rupees	346.34	2.96	1.135	2.61
		Labor	Man-Days	80.10	9.90	14.00	0.71
		Bullock Power	Hours	41.06	- a/	5.00	-
		Tractor Power	Hours	2.56	- a/	10.00	-
Tail	38	Canal Water	Acre Inches	23.71	-37.11	6.00	-2.32
		Tubewell Water	Acre Inches	4.61	- a/	16.00	-
		Cash Inputs	Rupees	290.92	3.02	1.135	2.66
		Labor	Man-Days	64.12	13.72	14.00	0.98
		Bullock Power	Hours	45.89	7.79 b/	5.00	1.56
		Tractor Power	Hours	1.87	- a/	10.00	-

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a/ Estimated coefficient is insignificant, but different from zero, so MVP cannot be interpreted.

b/ Estimated coefficient is significant at the 20 percent level.

cent of time (hours received through warabundi) traded, and a dummy variable for watercourse improved, as presented in Equation VI.7.

$$\% \text{ of Time Traded} = 6.16 + \underset{(.17)}{.36D} \qquad (VI.7)$$

$$r^2 = .0002 \quad n = 126 \quad F = .03$$

(D: 1 = improved watercourse; 0 = control watercourse)

ANOVA results, on the other hand, indicate that there is some tendency for more active traders to be located on improved watercourses, and for inactive traders to be on unimproved watercourses (see Appendix D, Table D-36). There is a stronger tendency for tubewell water users to be located on improved watercourses, and for non-tubewell water users to be on unimproved watercourses (see Table D-2c). No apparent relation is demonstrated either way for the types of warabundi practiced on internal watercourses and the types of watercourses (Table D-4a). However, a strong relationship is demonstrated in the three-way interaction between tubewell water use, kachha internal warabundi and watercourse improvement (Tables D-6b and V-10); and an even more remarkable four-way interaction is shown between the methods of farmer control studied here tubewell water use, active trading, kachha internal warabundi and watercourse improvement (Tables D-10a and V-10).

The major implications from this important test are that all methods are able, by varying degrees, to increase control and flexibility over water supplies, and that their four-way (joint) interaction effect greatly impacts productivity and gross income per acre, as one means of control reinforces the other.

Since statistically strong correlations were demonstrated in Chapter V between cooperation (as measured through the number of collective projects initiated in the last five years on the watercourse level) and gross incomes per acre, canal water trading and the type of warabundi practiced on internal watercourses, it would be interesting to examine the correlation between cooperation and watercourse improvement as well.

Equation VI.8, below, demonstrates that using regression techniques a very strong relation exists between these two variables.

$$\text{No. of Collective Projects} = 0.6 + \underset{(3.18)^{***}}{1.8D} \qquad \text{(VI.8)}$$

$$r^2 = .36 \qquad n = 20 \qquad F = 10.125^{***}$$

(D: 1 = improved watercourse; 0 = control watercourse)

These results indicate that an average of three times as many collective projects exist on improved watercourses as on control watercourses. However, given that one of the collective projects counted here is watercourse improvement itself, the average number of collective projects, other than watercourse improvement, is double that of control watercourses.

ANOVA results generally support this finding: there is a marked tendency for improved watercourses to have more than average number of collective projects, and for unimproved watercourses to have one or no collective projects (Table D-5). Also, there are strong tendencies for tubewell water users, active traders and the practice of kachha internal warabundi to occur more frequently on improved, and more cooperative, watercourses (see Tables D-7b, 8c, 9b, 10g, 11a and 11b).

Benefit-Cost Analysis of Watercourse Improvement

The apparent lack of any substantive benefits of watercourse improvement on crop production and gross incomes per acre renders the benefit-cost analysis of little moment, although data on the costs to farmers and to the project of watercourse improvement are interesting in themselves. Results from this section can also be used for handy comparison with other benefit-cost studies of OFWM watercourse improvement.

The lack of major benefits exhibited through the production function or through analyses on mean per acre gross incomes, while disturbing from an economic-return-to-the-project point of view, may not be surprising given the nature of the sample. For one thing, watercourses in the general Faisalabad area, near major paved roads and organized agriculture-related markets, and in generally non-waterlogged and non-saline areas appear to have relatively high cropping intensities even before watercourse improvement (as indicated on control watercourses). Also, increased crop yields and production are functions of several critical inputs, including the unmeasured farming (cultural) practices and management components; yet watercourse improvement only addresses the canal water input directly, and the tubewell water input indirectly, by decreasing conveyance losses. The OFWM Project also has precision land levelling farm extension components, but these have not been exercised on any of the sampled improved watercourses.

Subsequent, tightly-controlled studies of OFWM watercourse improvement may, in fact, reveal substantial benefits from the project in generally waterlogged and saline areas, in areas and on watercourses where cropping intensities tend to be lower, in areas of sandier soils and more erratic slope conditions between head and tail watercourse reaches, in areas further from major paved roads and organized agriculture markets, and in areas where precision land levelling and active farm extension work by OFWM personnel are taking place in conjunction with watercourse improvement. However, as this study has shown, it will prove virtually impossible to find any improved watercourses in the immediate Faisalabad area meeting these other criteria, and it may prove difficult to find any in other regions of Pakistan as well.

There is some difference exhibited in gross incomes per acre on 1977/78 and 1979/80 improved watercourses, suggesting that some direct, crop-related benefits may begin appearing in some unknown future year. But it can also be argued that if direct benefits from watercourse improvement are still not appearing three or four years after completion of the actual improvement work (since gross incomes per acre are not noticeably different between 1977/78 improved watercourses and control watercourses), they will not likely appear later on either. By three or four years after improvement, it can be hypothesized that farmers must have adjusted their cropping patterns and intensities and corresponding input uses to any changes in irrigation water conveyance efficiencies. Also, the improvement themselves, both earthen and concrete, will begin to slowly deteriorate over time, minimizing gains realized in conveyance efficiencies.

The total costs to farmers and to the OFWM Pilot Project of sampled improved watercourses are summarized in Table VI-10, below. The costs to farmers are the reported sum of masons and other hired labor expenses in the construction of brick and concrete lined sections,

Table VI-10. Estimated Costs to Farmers and the OFWM Pilot Project of Watercourse Improvement on Sampled Improved Watercourses in the Faisalabad Area.

Water-course or moga No.	Total cost to farmers (Rs.)	Length of earthen improved w/c (meters)	Length of concrete lined section (meters)	No. of concrete nakkas	No. of culverts (Total)	No. of buffalo wallows	Total cost to OFWM-USAID (Reimbursement Value) (Rs.)	Total cost of the Project (Farmers' Cost +OFWM-USAID Cost) (Rs.)
1	17,515	3,352	125	40	6	3	37,284	54,799
2	23,480	2,528	525	25	4	3	80,545	104,025
3	13,950	2,497	232	26	6	0	36,206	50,156
4	11,200	1,909	46	16	2	0	18,907	30,107
5	16,960	2,111	402	12	2	0	55,554	72,514
6	16,080	2,109	383	34	5	1	53,446	69,526
7	33,460	3,933	732	60	14	0	126,466	159,926
8	26,490	3.340	345	35	6	0	65,568	92,058
9	29,660	4,150	491	33	6	0	87,221	116,881
10	18,925	2,573	305	21	1	0	50,278	69,203
Total	207,720	28,502	3,586	302	52	7	611,475	819,195
Mean	20,772	2,850	359	30	5	0.7	61,148	81,920

nakka outlets, culverts and buffalo bathing tanks, and an estimate of the total labor expense incurred by the irrigators themselves through their own labor efforts in the earthen improvement work. These own labor costs are reflected by reimbursement values received by OFWM from the USAID Mission to Pakistan, for earthen improvements, at the rate of Rs. 4.76 per earthen improved meter. This rate is roughly equivalent to a shadow wage rate of Rs. 15 per day.

The costs to the OFWM project are the total reimbursement values reported received by OFWM from USAID, based upon the rates of Rs. 4.76 per earthen improved meter, Rs. 103 per concrete lined meter, Rs. 237 per concrete nakka, Rs. 628 per pipe culvert, Rs. 286 per cubic meter of other culverts, and Rs. 2000 per buffalo wallow. The cost figures to the OFWM project do not include personnel salaries and other fixed expenses since these are assumed to be covered, in part at least, by the added allowance for earthen improved lengths (only personnel expenses are realized by OFWM for earthen improvements).

With no benefits exhibited on sampled watercourses of watercourse improvement, and assuming no added costs beyond the initial (base = 0) year in the form of maintenance (since irrigators would engage in watercourse cleaning and maintenance programs with or without watercourse improvement), the net present value of an average improved watercourse is -81,920 rupees. The benefit-cost ratio is zero.

Summary

Based on the results discussed in this chapter, OFWM watercourse improvement does not appear to have substantially affected control and flexibility, nor have a major impact on productivity. While water supplies and crop production both increase somewhat, statistical tests do not decidedly support the thesis that watercourse improvement improves conveyance efficiencies.

Other tests between watercourse improvement and other farmer methods to obtain control and flexibility over water supplies reveal a direct relationship to tubewell water use, and this may be due to a sampling bias. However, strong relationships are demonstrated using ANOVA between watercourse improvement, tubewell water use, active trading and kachha internal warabundi. High correlation is also demonstrated between watercourse improvement and the element of cooperation on the watercourse.

The major findings and implications of this research effort may now be summarized in the concluding chapter.

CHAPTER VII

SUMMARY AND CONCLUSIONS

In this final chapter the major findings of this research are briefly summarized. The limitations of this study are also included. Finally, some suggestions for further research in irrigation water distribution and management are advanced.

Summary

Private tubewells, canal water trading, flexible warabundi and OFWM watercourse improvement all represent important options for farmers to increase control and flexibility in water supplies in Pakistan. The literature is generally lacking in discussing specific options to farmers to gain this control. Consequently, this study provided detailed descriptions of the rotational warabundi distribution system, in conjunction with supplemental tubewell water supplies and trading of canal water turns. The literature also provides conflicting evidence of the impact of watercourse improvement on productivity. This specific government project was also a major topic addressed in this research, as another potential method of control along with the three indigenous methods indicated above.

In order to do this, a sample of 130 farms and farmers on 20 watercourses were collected in the Faisalabad, Punjab, perennial canal-irrigated and private tubewell water supplemented area. The isolated impacts of each of these methods on both productivity (as measured by gross income per acre) and cooperation (as measured by the number of watercourse-level collective projects initiated within recent years) were statistically estimated and quantified (in rupees). Important interrelationships between the various methods of control were also conceptually developed and statistically estimated. A small, controlled study of this nature enabled the collection and analysis of high quality data, which is not typically present in a broad study.

Major results can be easily visualized with the help of a diagram. Figure VII-1, below, captures many of the key conceptual and empirical interrelationships between the four farmer options of flexibility examined, and the dependent variables gross income per acre and cooperation. Significance levels, however, must not be inferred to a larger population because of the non-random nature of the sample.

The strongest correlations with gross income per acre are with canal water trading and per acre tubewell water use. Kachha internal warabundi and watercourse improvement, however, demonstrate very weak positive correlations with per acre gross income. These results are supported by ANOVA results as well (see Table V-10). But significance levels do not tell the whole story.

Relatively more flexibility is gained through stricter control over tubewell water use, as shown in Table VII-1, below, with respect to gross incomes per acre among actual tubewell owners and users of singly-owned tubewells (in comparison to users of joint property tubewells). Table VII-1 presents different categories of sample farms, sub-sample sizes, mean per acre gross incomes and standard deviations,

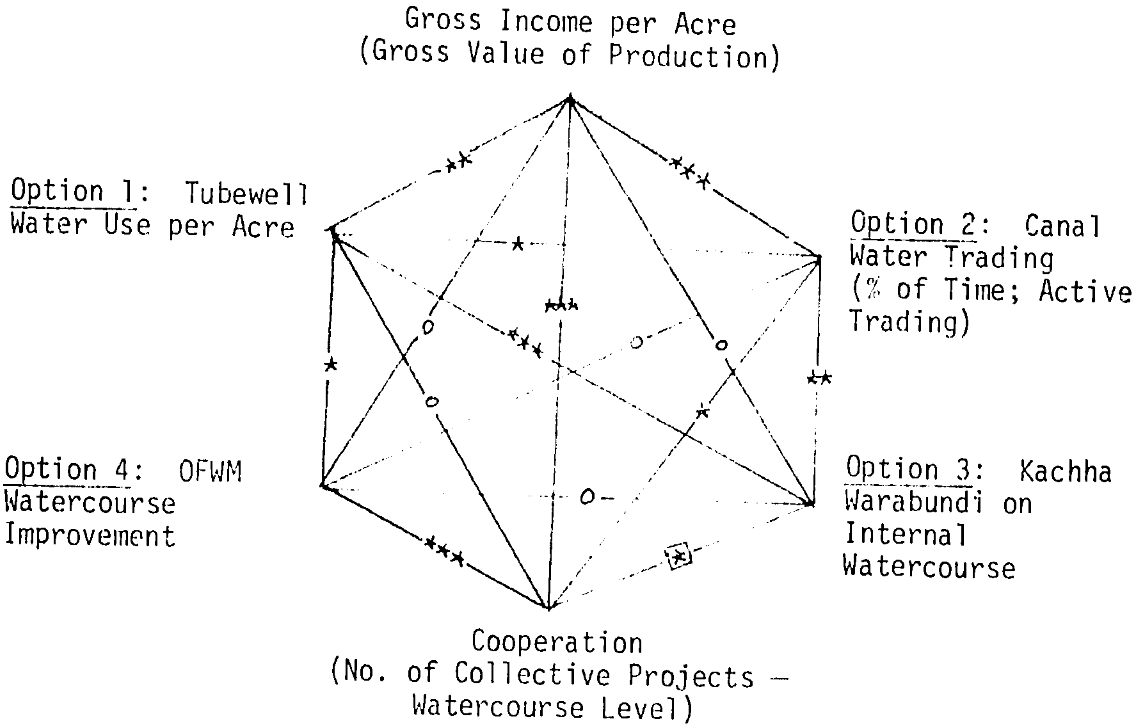

Figure VII-1. Statistical Correlations Between Six Variables, Including Gross Income per Acre, Cooperation, and Four Farmer Options for Increased Control and Flexibility in Water Supplies.

0 = No apparent significant correlation.
$\boxed{*}$ = Significance at the 15 percent level.
* = Significance at the 10 percent level.
** = Significance at the 5 percent level.
*** = Significance at the 1 percent level.

Table VII-1. Gross Incomes per Acre (mean and standard deviation) Arranged in Descending Order for Different Sub-samples of Farmers, 1980-81, with Respect to Tubewell Water Users, Traders, Internal Warabundi Practicers, Type of Watercourse and Total Sample.

Sub-sample category	No. of observations	Gross Income per Acre (Rs.)	
		Mean	Std. dev.
Tubewell owners	10	4059	2029
Singly-owned tubewell users	32	4019	1738
Active traders	42	3828	1759
Electric-powered tubewell users	44	3688	1718
"Older" (1977-78) improved watercourses	38	3679	1415
Diesel-powered tubewell users	16	3422	1856
Kachha internal warabundi practicers	77	3343	1451
Pakka internal warabundi practicers	52	3228	1473
"Newer" (1979-80) improved watercourses	27	3205	1596
Joint property tubewell users	28	3157	1629
Control (unimproved) watercourses	64	3108	1391
Inactive traders	71	3048	1196
Total sample	129	3297	1453

arranged in descending order of mean per acre gross incomes. This is a descending order of a priori expected effect on control as well.

Overall, then, the stricter control and increased flexibility obtainable through tubewell water use appears to have the most significant impact on gross income per acre, followed closely by the increased flexibility over water supplies obtained through active trading.

Production function results, in fact (as summarized in Table VII-2, below) indicate that use of singly-owned tubewell water and active trading represent the methods tested with greatest effect on control and flexibility; followed in relative order of importance by tubewell use, per se, kachha internal warabundi and OFWM watercourse improvement. Table VII-2 presents findings on the percentage change in estimated R^2's between sub-categories of farms and F-statistics to test for differences in sub-category production functions, both measures of the impacts of available farmer options on control.

Table VII-2 also indicates that in every case of paired sub-sample production function estimations the marginal value product of per acre cash inputs increased with an increase in control; as shown in the last column of "percentage change in estimated elasticities of cash inputs per acre." Production function results also indicate that, in general, for all farm categories, the inputs of tractor power, cash inputs and tubewell water are grossly underutilized, and that crop production could be substantially increased with simultaneous increase in the use of these factors.

As indicated in Figure VII-1, above, correlations between the four farmer options are most pronounced between tubewell water use and the practice of kachha internal warabundi, and canal water trading and

Table VII-2. Percentage Change in Estimated R^2's, Covariance Test F-Statistics and Percentage Change in Estimated Elasticities of Cash Inputs per Acre with Respect to Contrasted Categories of Farms.

Category	Percentage change in estimated R^2's	Covariance test F-statistics	Percentage change in estimated elasticities of cash inputs per acre
1. Tubewell water versus non-tubewell water using farms	23	1.63	93
2. Singly-owned versus joint property owned tubewell using farms	3	3.40***	80
3. Active versus inactive trading farms	97	3.38***	124
4. Kachha versus pakka internal warabundi using farms	26	1.50	81
5. Farms on improved versus control watercourses	17	0.94	-8

***Significance at the 1 percent level.

kachha warabundi. Weaker correlations are demonstrated between tubewell water use and trading, and tubewells and OFWM watercourse improvement (although it could just be a coincidence that watercourse improvement takes place on watercourses with private tubewells present). ANOVA results, however, indicate a very strong two-way interaction between tubewell water use and trading on production (see Table V 10 and supporting Table D-2a).

The three-way relationship (Figure VII-1) between tubewell water, trading and kachha warabundi is particularly revealing: small-scale trading, made easier on internal watercourses where kachha warabundi is practiced with fellow irrigators, appears to act in a complementary way with tubewell water use in the acquisition of irrigation water supplies during high transient peak demand periods of crop stress and high evapotranspiration. ANOVA results (Tables D-6a and V-10) indicate that the relationship between tubewell water use and trading is stronger for kachha internal warabundi practicers; and the interaction effect of the three on gross income is significant.

Tubewell water use and cooperation are highly correlated with production, and gross incomes per acre are very significantly higher on watercourses with a greater number of collective projects. The relationships between tubewell water use and trading, on the one hand, and trading and kachha internal warabundi, on the other, are made stronger on watercourses with more than average number of collective projects; as shown by the data in Appendix D, Tables 8(a) and 8(b), and the significant three-way interactions with gross income per acre in Table V-10.

A very strong correlation is demonstrated between all four local farmer options considered here (see Tables D-10a and V-10). Highest mean per acre gross income is being realized, in general, by the group of (singly owned) tubewell water users, who actively trade canal water, who practice kachha internal warabundi and are located on OFWM improved (main) watercourses. Lowest mean per acre gross income, on the other hand, is being realized, in general, by the group of non-tubewell water users, who either do not trade or only inactively trade, who practice pakka internal warabundi and are located on unimproved watercourses. Apparently all four methods are able, by varying degrees, to gain added control over water supplies. Their four-way interaction greatly effects productivity and gross income per acre, as the methods reinforce each other.

Limitations of the Study

The major limitations of this study have already been alluded to, but it is worthwhile to summarize them here:

1. The sample of OFWM improved watercourses is small, confined to roughly a 12-mile radius area around Faisalabad city where small farmers, perennial canal water and frequent tubewell irrigation, high cropping intensities and organized markets for inputs and outputs predominate. No sampling took place in other OFWM project areas (in or out of Punjab), on non-perennial canal systems, in generally waterlogged and saline areas, or on head or tail positions on a given major or minor canal system.

2. There is reason to expect that the estimates of coefficients using the Cobb-Douglas production function approach are both biased and

inconsistent, mainly due to the presence of simultaneous equation bias (Sampath, 1979). Efforts to eliminate this bias were unsuccessful (see also Koutsoyiannis, 1977). Attempts to minimize aggregation and mis-specification biases and improve upon the efficiency of estimates were largely successful through careful and thorough sampling procedure and data collection.

3. The sample includes only pakka warabundi (main) watercourses. Insufficient numbers of adequate kachha warabundi watercourses to act as controls prohibited comparison with pakka warabundi watercourses in the sampled area, or in two other pre-tested areas of Punjab.

4. There is a bias in the sample toward internal kachha warabundi (i.e., on the internal watercourses, within the squares or marabas), with relatively few sampled watercourses with pakka warabundi on the internal (as well as on the main) watercourses.

5. There is a strong bias for sampled improved watercourses to have one or more electric-powered tubewells, or no tubewell at all, and for the sampled control watercourses to have one or more diesel-powered tubewells, or no tubewell at all. Due to significant price differentials there was consequently more tendency for farmers on improved watercourses to use tubewell water in 1980-81. Control for this bias is made through the production function, but it unfortunately affects certain other non-production function comparative analyses.

6. A bias exists in comparative tests between ownership patterns of tubewells, due to the fact that all sampled cooperatively-owned tubewells are located on improved watercourses. Extensive search revealed no cooperatively-owned tubewells on any but improved

watercourses in the sampled area. However, some comparisons can be made when neutralizing for the effect of watercourse improvement.

Suggestions for Further Research

This study has highlighted several important methods of farmer control and flexibility in water supplies. It has also specified deficiencies in the literature on this subject and brought into focus some issues of concern which were outside the predetermined realm of the research. These issues may develop into separate research endeavors, and are summarized below.

The high value of water control and timing on productivity, as suggested by this research, warrants continued study of control issues in other areas of Pakistan. Contrasts could be made, for example, between waterlogged and saline soil areas (i.e., SCARP versus non-SCARP zones – see Glossary for definitions), perennial and non-perennial canal irrigated areas, areas solely dependent on tubewell water supplies and areas either dependent upon canal water alone or canal and tubewell water supplied areas (or both), "biarani" (rainfall only) and other areas, mountainous and other areas, and different relative major and/or minor canal command locations.

Essentially, results from this study suggest an extended research of the issue of local control of irrigation water through a major survey. This survey would be based on random watercourse and farm sampling techniques to permit broad tests of significance and extensive modelling efforts with extensive policy making implications. The issue of local water control and OFWM watercourse improvement would be better served through a separate major survey, based, again, on random selection of improved watercourses, control watercourses and farms.

The disappointing lack of substantive benefits from watercourse improvement exhibited in this study indicates that closer examinations of the project are in order. Watercourse improvement, and OFWM activities in general, should be investigated thoroughly in other areas of Pakistan, as well; including all the above-mentioned types of areas. However, strict controls need to be made in the selection of sample watercourses and farms.

In this connection, the issue of optimal lining of watercourses (and canals as well) needs to be rigorously addressed, with emphasis paid not only to impacts on conveyance efficiencies but also to crop productivity and farm incomes. It is possible that watercourse improvement can be re-examined regarding optimal lining policy. Results from Table VI-2 tentatively show that watercourse improvement results in significantly higher canal water use per acre for sampled head and middle farms, but not for tail farms. It will be remembered that most lined sections are at the head of improved watercourses.

The economic returns to canal and open drain rehabilitation projects (such as the currently budgeted World Bank project, 1982) need to be accurately quantified before proceeding in efforts of this type. A distinction needs to be made between benefits to productivity and flood control. Moreover, it is possible that what would help most is well timed canal water supplies, even to the extent that increases in canal water supplies has a negligible or negative effect at certain times.

Studies of village and watercourse cooperation are in order to better understand the differences of pakka and kachha warabundi, both on main and internal watercourses, in their impact on water control and flexibility. Their inter-connections with tubewell water use and trading of canal water turns can also be better documented. Kachha warabundi inherently represents the potential of increased flexibility over pakka warabundi, but the problems of administering it, as suggested by Mirza and Merrey (1979) and this study, need to be understood in more detail and perhaps overcome to some extent.

The issue of pricing canal water more efficiently to reflect its actual cost needs to be studied in detail to facilitate improvements in the canal system. Production function results from this study indicate a general over-use of canal water at all relative watercourse command positions. A revision of abiana water rates or a form of volumetric pricing may be in order to encourage more efficient use. However, given the apparent difficulties encountered in administering local institutions, volumetric pricing may also prove hard to administer. Setting an annual abiana tax rate per authorized c.f.s. discharge, and letting the farmers come up with the set amount on their own (preferably on a per acre basis), may represent a viable alternative.

Overall pricing and supply policies need to be further researched, with respect to crop and other output prices and input prices and supplies, such as diesel fuel, electricity, fertilizer, seeds, etc. Important linkages were shown in this study, for example, between fertilizer use and local control methods.

Because private tubewells represent such important aspects of indigenous farmer control of water supplies, policies affecting continued use and expansion of private diesel- and electric-powered tubewells (and diesel-powered tractors as well) need to be studied in considerable more detail. In particular, a lowering of the artificially high price of diesel fuel may be in order, by partially obtaining government tax revenues elsewhere, with theoretically favorable impacts on: (1) diesel tubewell investments and use; (2) diesel tractor investment and use; and (3) truck and other transport use, with important implications for increasing agriculture market forward- and backward-linkages.

Further research may also find that encouragement of soft loans for investments in tubewells may significantly raise productivity in sweet-groundwater areas. If this hypothesis is substantiated, such loans could possibly be expanded to include investments in smaller capacity, "fractional" tubewells. Fractional tubewells have the advantage of encouraging single family ownership, also putting relatively more control in the hands of farms. They likely have the disadvantage, however, as opposed to larger capacity tubewells, of lack of economies in installation and operating costs.

The possibility of encouraging other small-scale surface water storage and reservoir systems, wherever topographically feasible, needs to be explored. Such localized systems could facilitate the establishment of local water demand systems and markets in rights to stored water. Also, added large reservoir storage capacity and power generation may be in order to partially stabilize the price of electricity, with important implications for electric-powered tubewell water use.

Conclusions

In conclusion, results from this study indicate that the increased flexibility over water supplies obtained through both tubewell water use and active trading of canal water turns have major impacts on productivity. These mutually supportive activities are reinforced, in part, by the other two sources of flexibility considered: kachha internal warabundi and watercourse improvement. The watercourse improvement program was not demonstrably successful in increasing either canal water supplies or productivity.

Major implications include the need for efforts to continue and expand private tubewell use. Also, a re-evaluation of the watercourse improvement program is in order.

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GLOSSARY

ABBREVIATIONS AND TECHNICAL, URDU AND PUNJABI TERMS USED

Abiana: Technically, a water rate, but in reality an indirect tax on canal water and a direct tax on assessed crop production.

Application Efficiency: The ratio, expressed in percentage terms, of water stored in the root zone divided by water applied to the field multiplied by 100. It can also be defined as:

$$\frac{\text{Total applied - Total overapplication}}{\text{Total applied}} \times 100.$$

Bharai: Added compensation time for conveying canal water downstream in a watercourse and filling a dry perimeter.

Biraderi: A brotherhood lineage group of families related through patriarcal ties within the same caste.

Caste: Ancestral, occupational grouping of people implying prestige graduations.

CCA: Cultural Command Area; the cultivated area of a watercourse command area which can be served by gravity irrigation.

c.f.s. or cusec: Cubic Feet per Second; a rate of water flow or discharge.

Chak: Block of (canal irrigated) land comprising the smallest administrative unit of Provincial Irrigation, Agriculture and Revenue Departments.

Chak Plan: A detailed Provincial Irrigation Department map of chak commanded area receiving canal irrigation.

Commanded or Irrigated Area: The area served by a watercourse or set of watercourses in a chak or village.

Conveyance Efficiency: The ratio, expressed in percentage terms, of the amount of water being discharged through a field outlet (nakka) to the amount of water flowing through the canal outlet multiplied by 100.

Cropping Intensity: The number of crops grown on a given field in a given year times 100 to express a percentage value. Applied to a farm, it is the acreage of all crops grown in a year divided by the area on which they were grown times 100. The maximum cropping intensity for two cropping seasons is 200 percent.

CSU: Colorado State University.

Distributary: The smallest water channel owned and maintained by the government. Chak and watercourse commands are divisioned off of either side of distributaries.

Gur: Indigenously prepared sugar from sugarcane crops.

Index Plan: A detailed Provincial Irrigation Department map of an administered canal irrigation division, typically being serviced by one or more minor canals.

Internal Watercourse: A secondary channel off of a main watercourse which irrigates fields inside a square of land, typically 25 acres. This watercourse is owned and maintained by all irrigators inside this square.

Irrigation Efficiency: The product of conveyance efficiency and application efficiency, commonly expressed as a percentage.

Irrigation Intensity: The ratio, usually expressed as a percentage, of the total land irrigated in a year to the total CCA multiplied by 100. The maximum irrigation intensity possible for two cropping seasons is 200 percent.

Jallar or Persian Water Wheel: An open well adapted to lifting groundwater through a chain of buckets or earthen pots powered by one or more bullocks, water buffaloes or camels in a horizontal circle.

Kachha: A word of multiple meanings, including unripe, impermanent, adjustable, random, unsanctioned, earthen, unimproved, poor quality; the opposite of "pakka."

Kachha Warabundi: A schedule of canal irrigation turn rotations informally agreed to by farmers without government interference or involvement.

Kanal: One-eighth of an acre.

Khal: Watercourse.

Kharif: Summer cropping season, from approximately mid-April to mid-October.

Killa: Area of land ranging from one to 1.1 acre.

Local: Person living, or whose family has lived, at present location before settlement of canal colonies in late 19th century and early 20th century.

Main Watercourse: Common farmer property watercourse channel extending from the government authorized or sanctioned canal outlet into the watercourse commanded area. This watercourse is sanctioned by Provincial Irrigation Departments and typically conveys water to each square of land in the commanded area.

Maraba: Square; a square of land typically comprising 25 one-acre parcels.

Marla: 1/160 of an acre or 1/20 of a kanal.

Maund: 82.28 pounds or 40 seers.

Moga (Mogha): Canal outlet, off of a distributary or minor.

Nakka: Field outlet, off of a watercourse. Also an outlet off of a main watercourse for discharge into an internal watercourse.

Nikal: Compensation time for emptying or draining off canal water left in a wetted perimeter of watercourse (section) at the end of a turn and closure at an upstream junction point.

Non-perennial: A single season, Kharif, canal water supply allocation for a watercourse commanded area.

OFWM: On-Farm Water Management; the USAID-funded Pilot Project under the Ministry of Agriculture and Cooperatives, Government of Pakistan. Designed objectives included watercourse improvement, precision land levelling and water management extension efforts.

Pakka: A word of multiple meanings, including ripe, fixed, permanent, predictable, sanctioned, concrete, improved, high quality; the opposite of "kachha."

Pakka Warabundi: A schedule of canal irrigation turn rotations under formal agreement through the Irrigation Department, based always on a rotation of seven days.

Panchayat: A village level council of elders and prominent villagers for local decision making and settlement of disputes.

Perennial: A year-round canal water supply allocation for a watercourse commanded area.

Rabi: Winter cropping season, from approximately mid-October to mid-April.

Rauni: Heavy, presowing irrigation.

Refugee: Person who migrated from present-day India at 1947 partition.

Sarkari Khal: Main watercourse.

SCARP: Salinity Control and Reclamation Project; areas where public tubewells are used for lowering water tables and augmenting water supplies.

Seer: 2.08 pounds or 1/40 of a maund.

Settler: Person who settled at present location during the opening of canal colonies.

Square: Typically, a 25 acre block of land.

Union Council: Political subdivision of a subdistrict.

USAID: United States Agency for International Development.

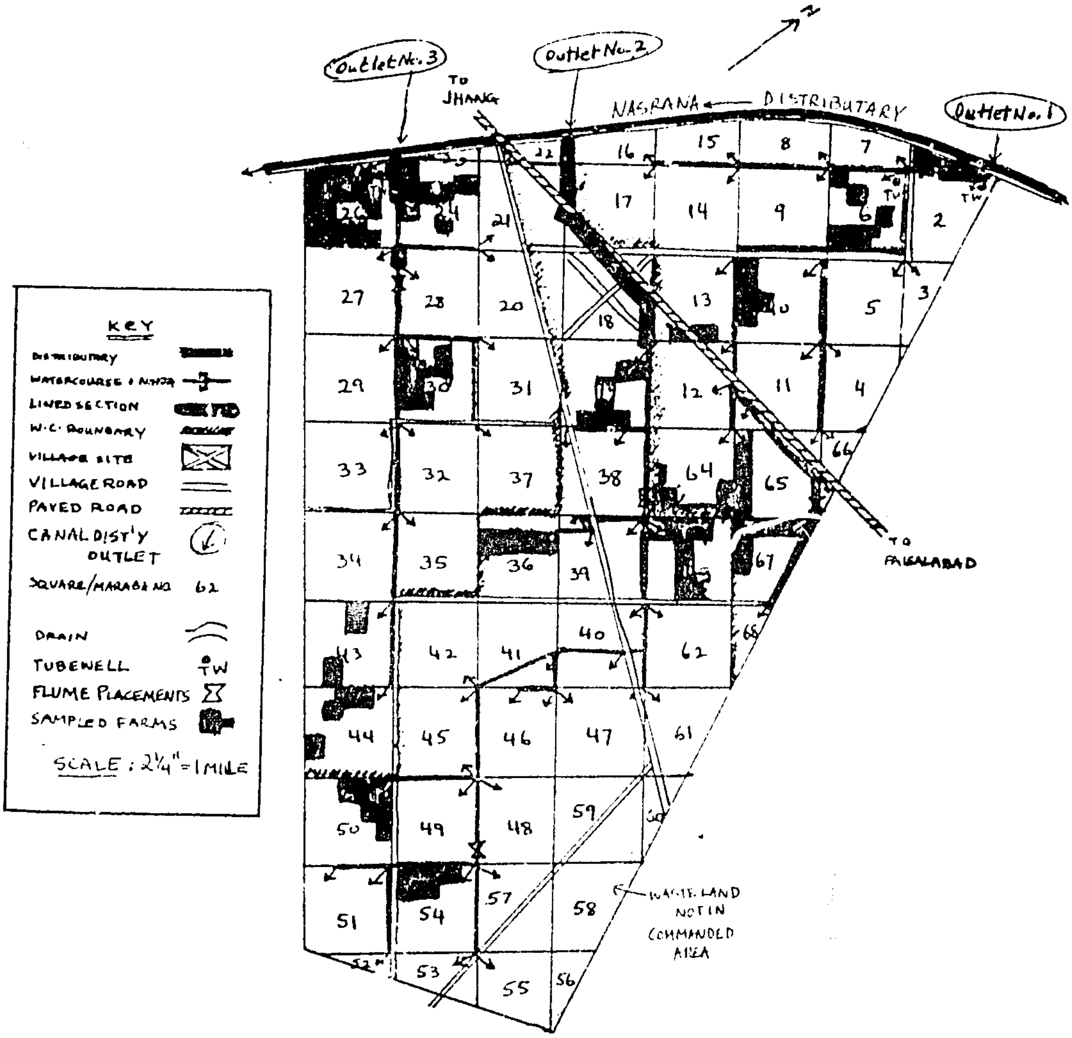
WAPDA: Water and Power Development Authority.

Warabundi: Schedule of canal irrigation turn rotations.

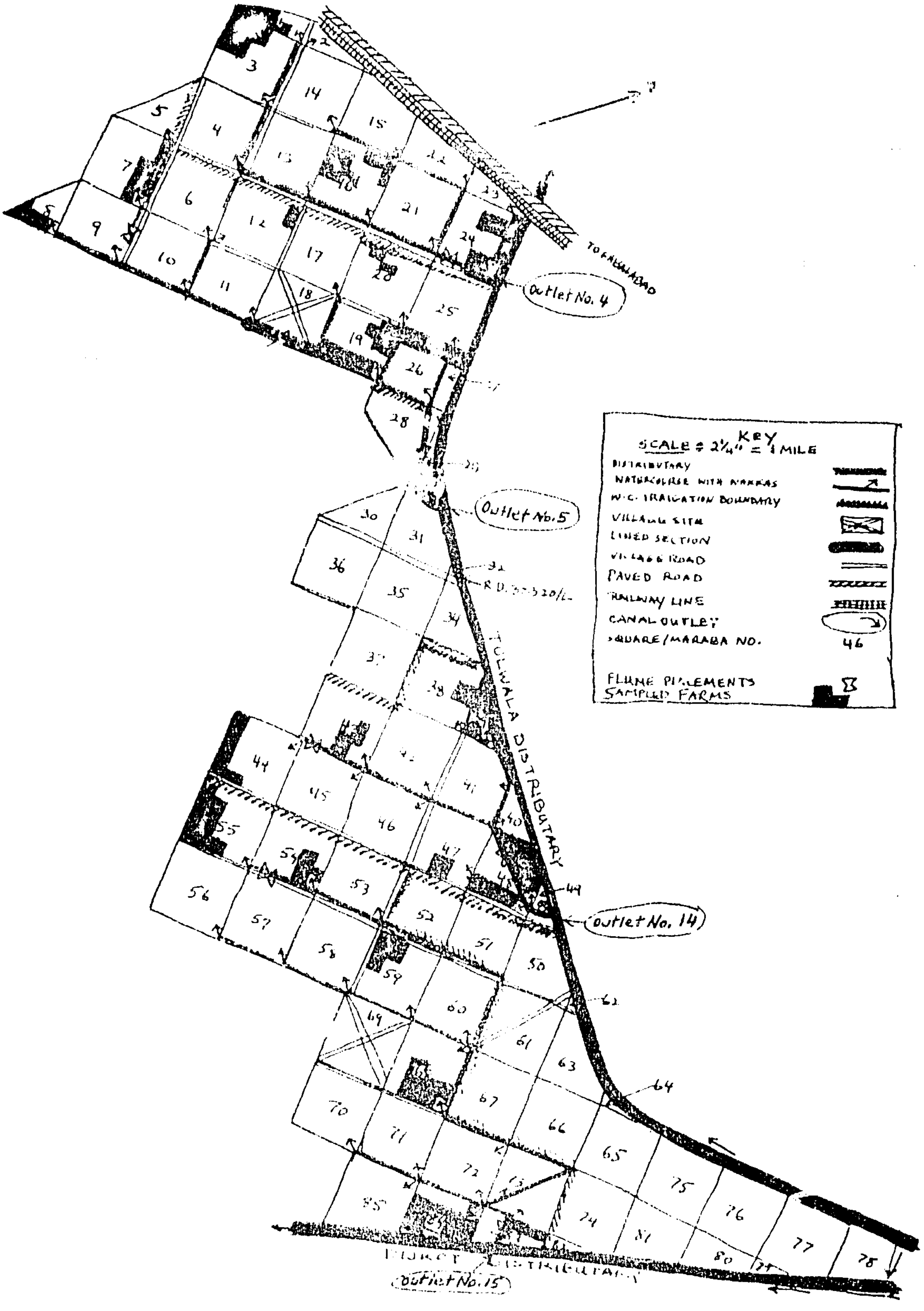
Watercourse: A common-property water supply channel, constructed, cleaned and maintained by farmers to convey water from a canal outlet or tubewell to a farmer's field.

APPENDIX A

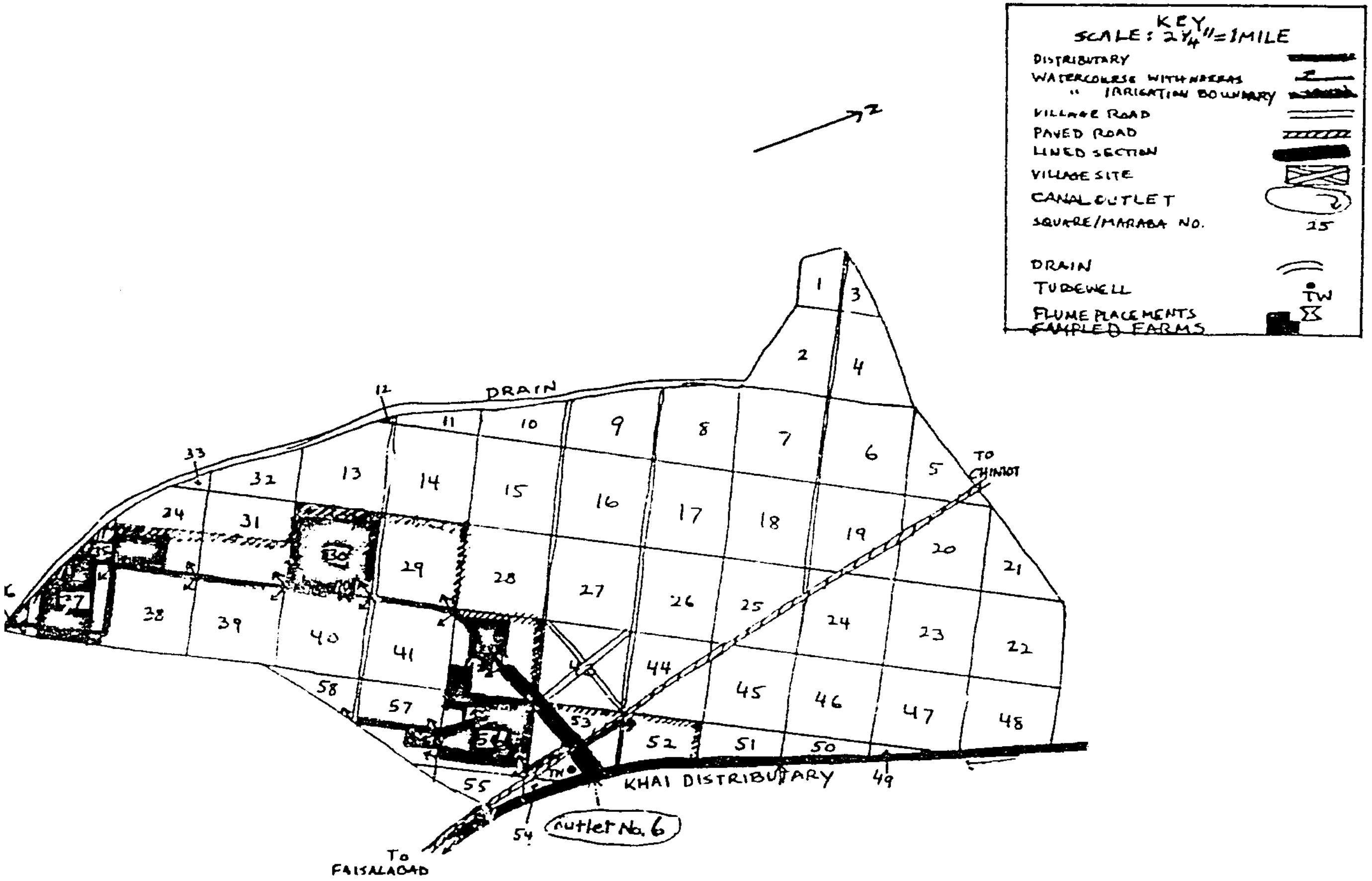
SAMPLE WATERCOURSE MAPS
(CHAK PLANS)



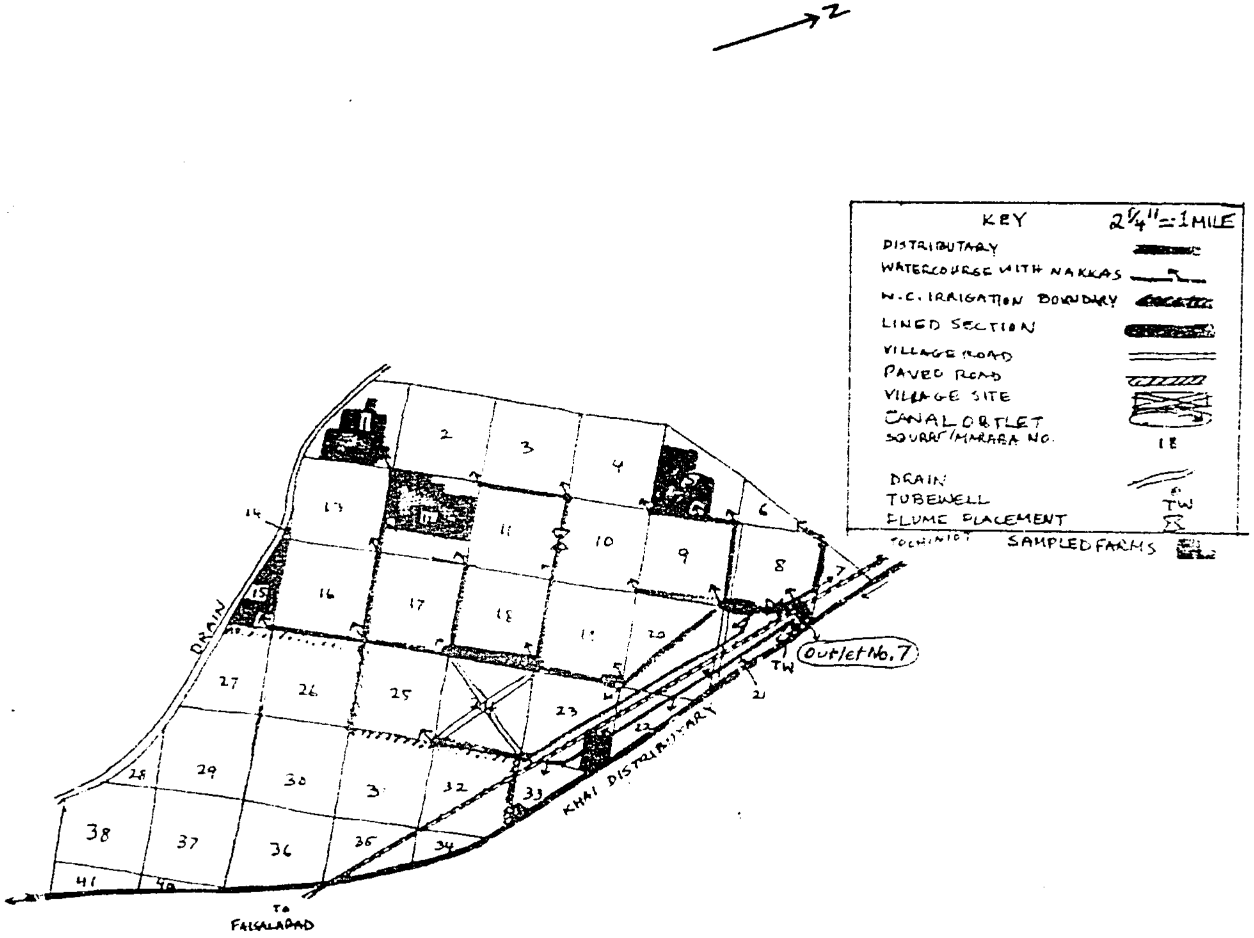
Map A-1: Sample Watercourse No.'s 1, 2, 3



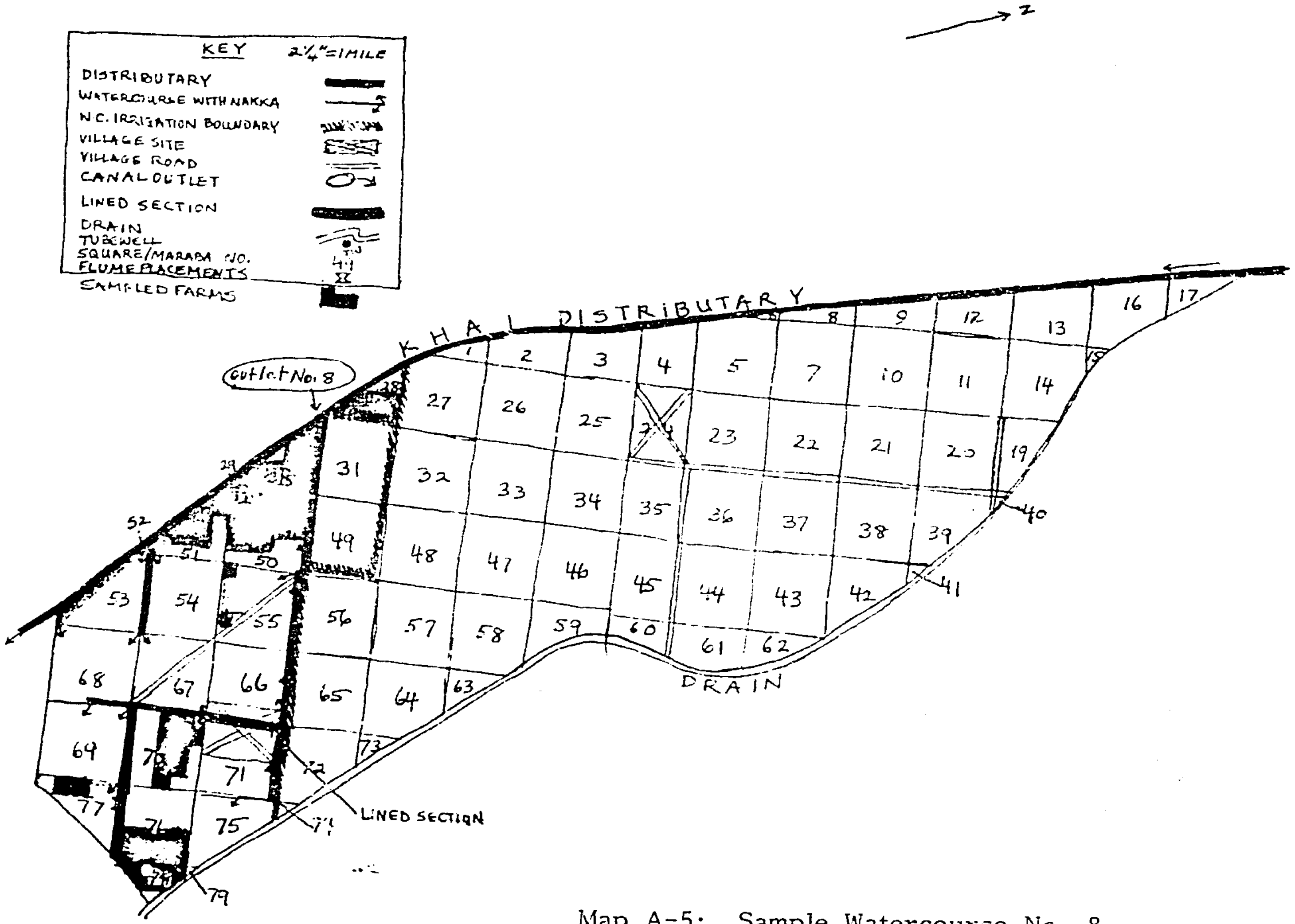
Map A-2: Sample Watercourse No.'s 4, 5, 14, 15



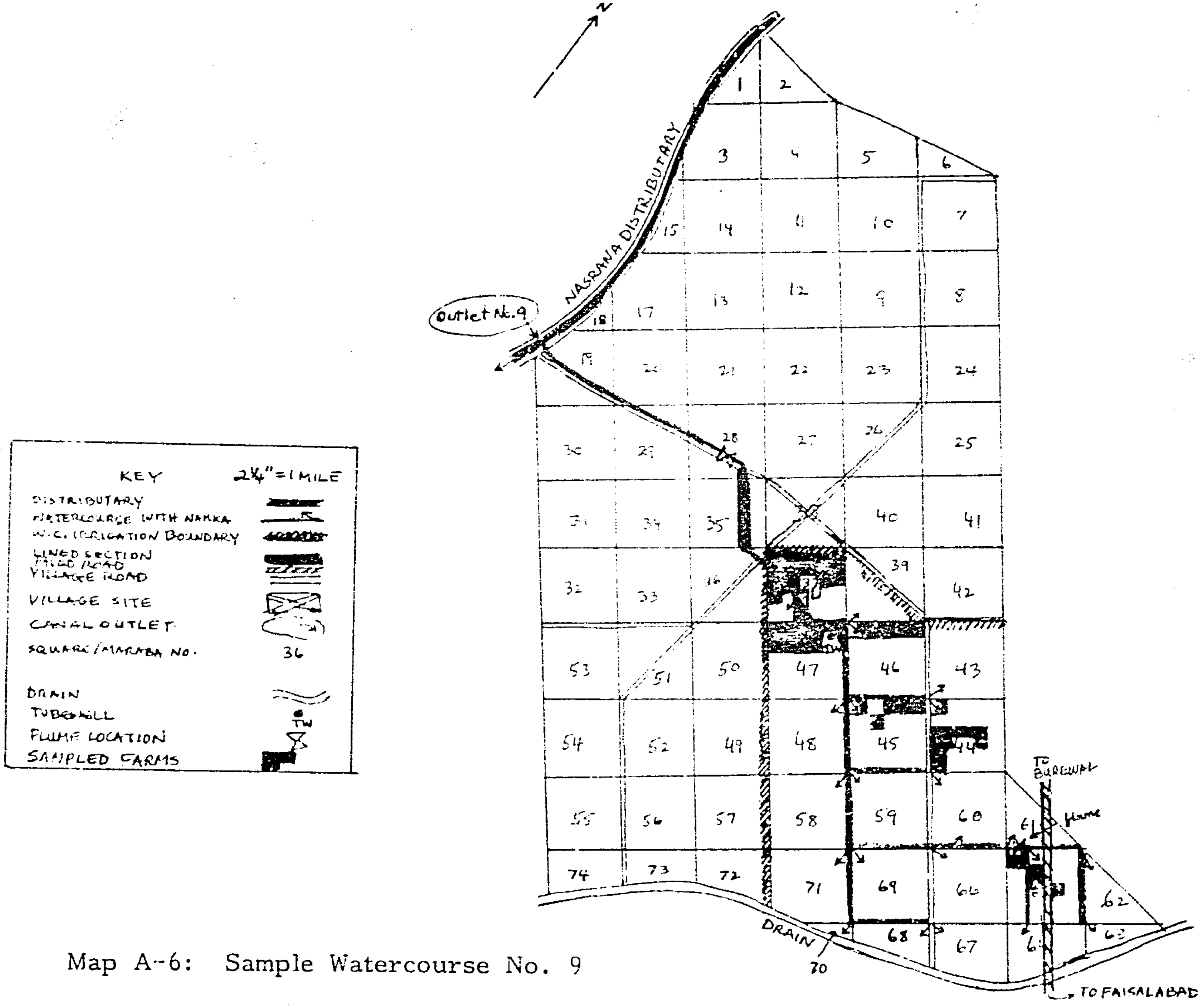
Map A-3: Sample Watercourse No. 6



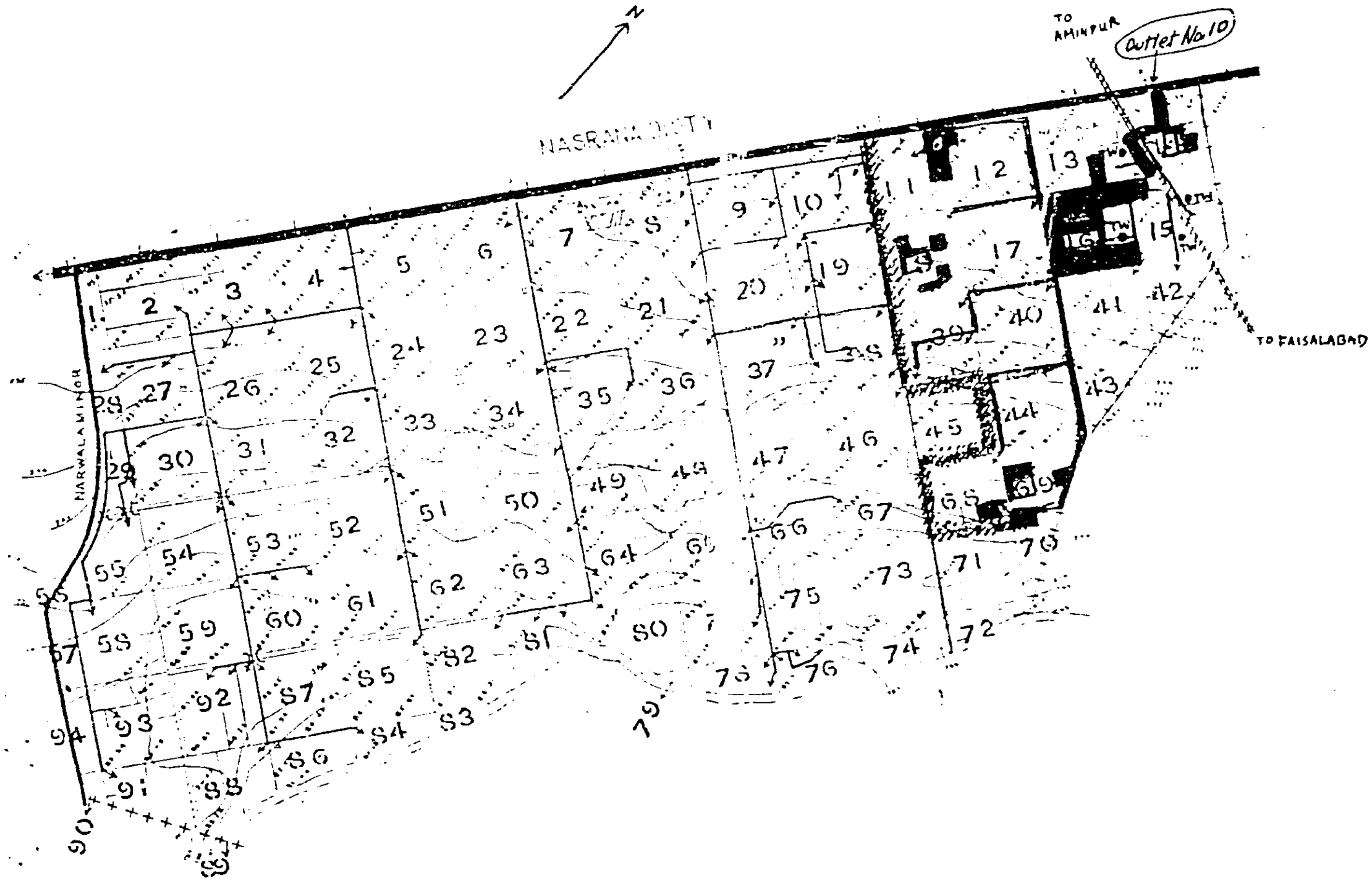
Map A-4: Sample Watercourse No. 7



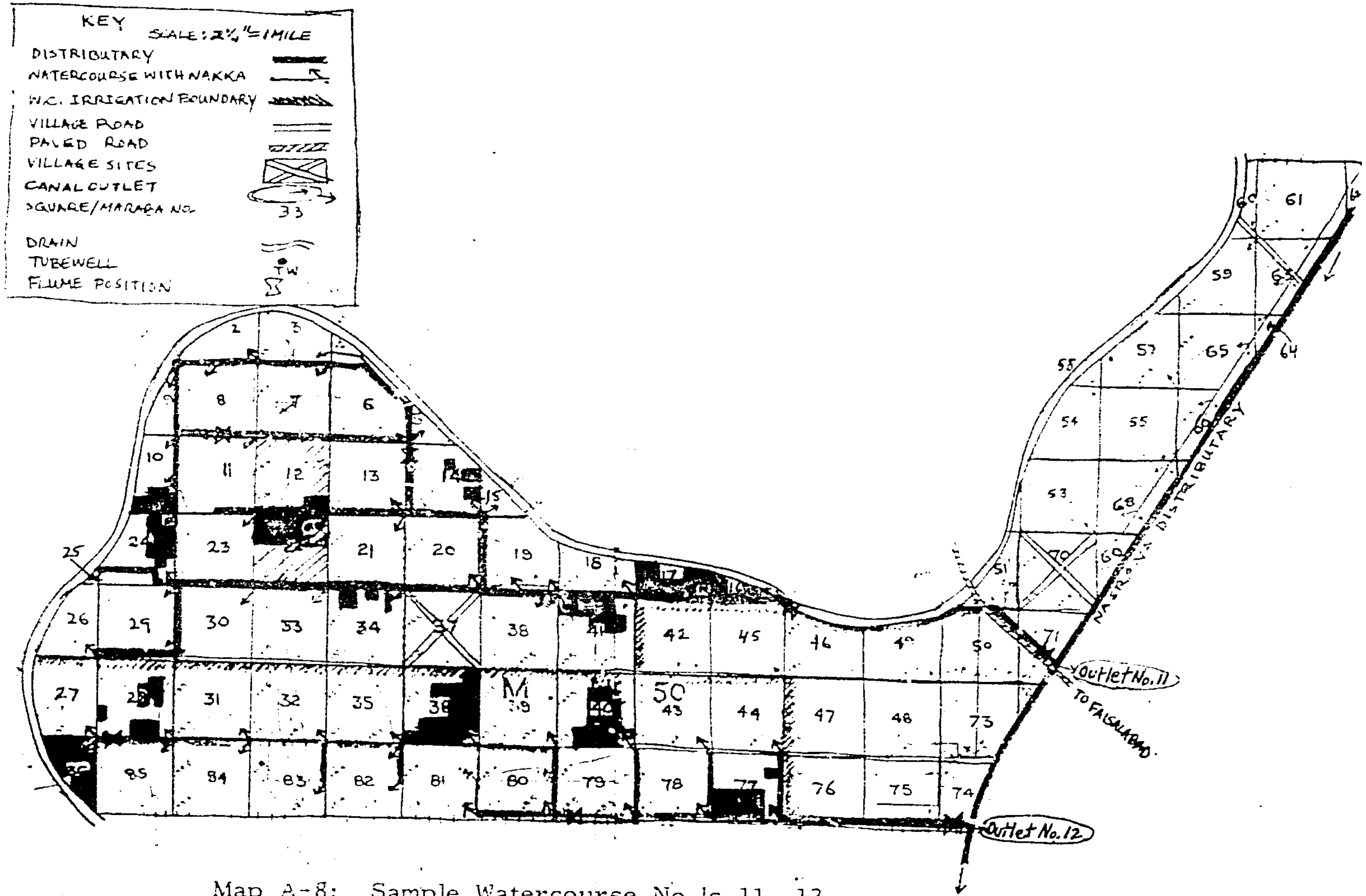
Map A-5: Sample Watercourse No. 8



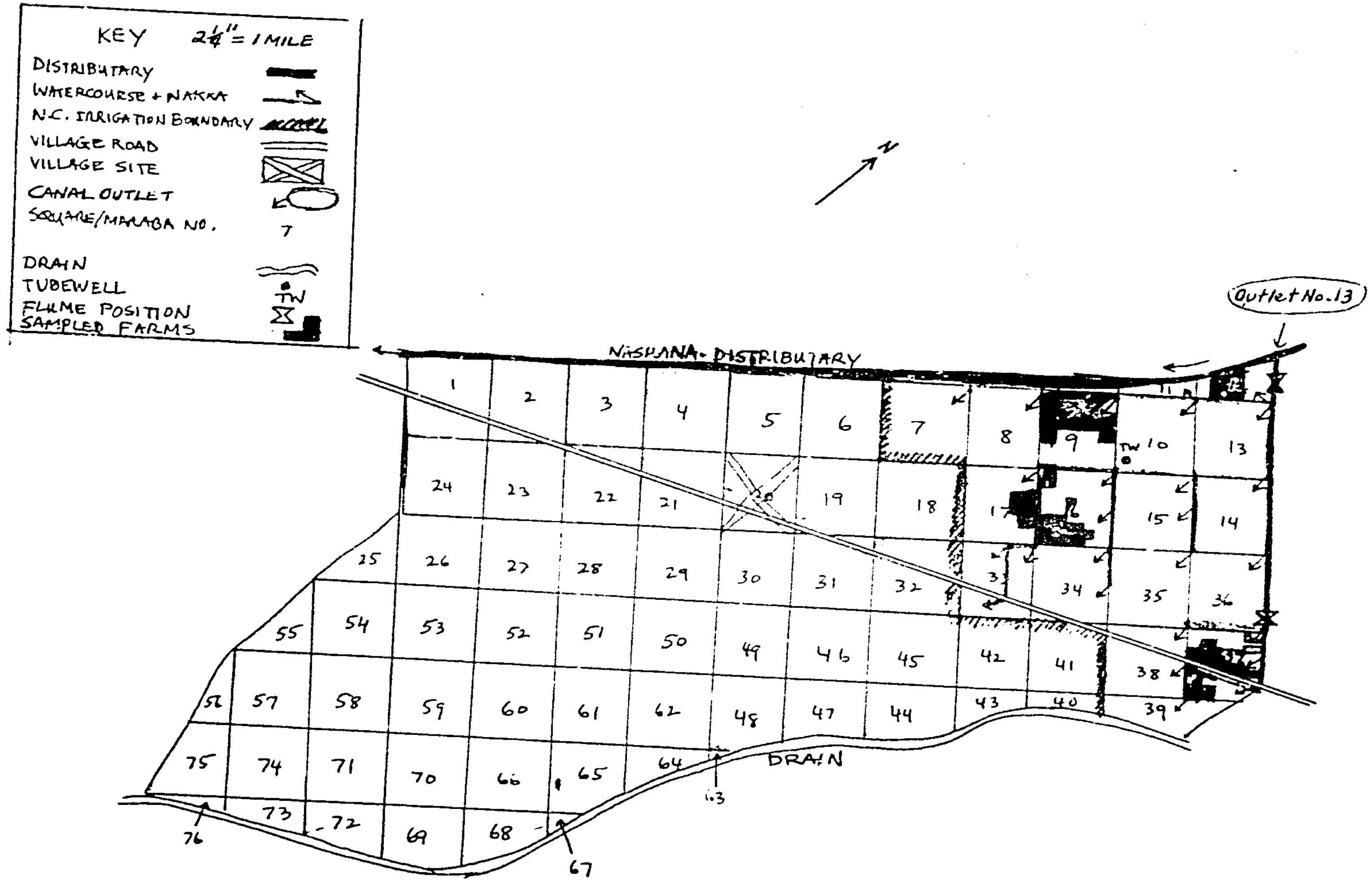
Map A-6: Sample Watercourse No. 9



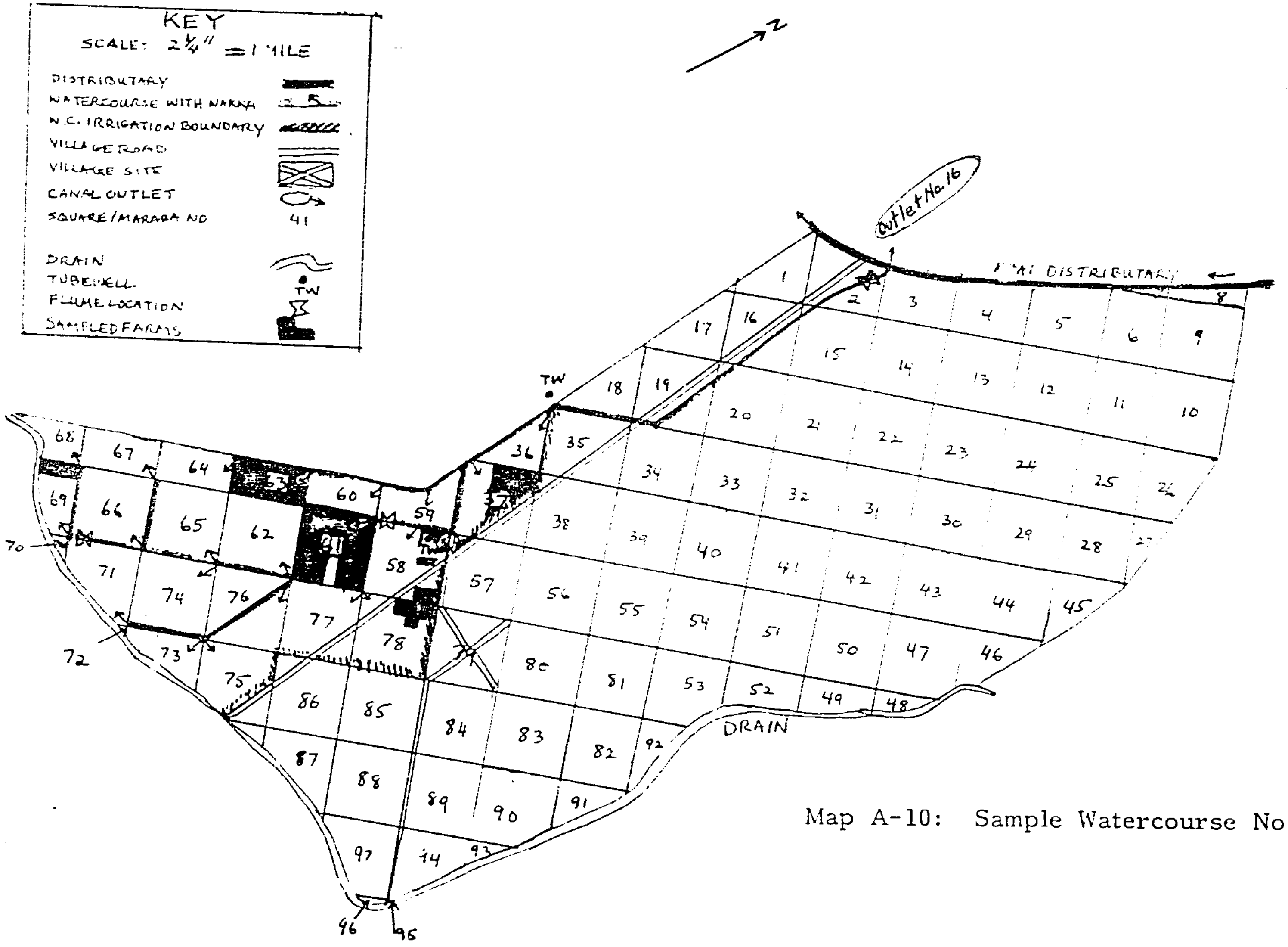
Map A-7: Sample Watercourse No. 10



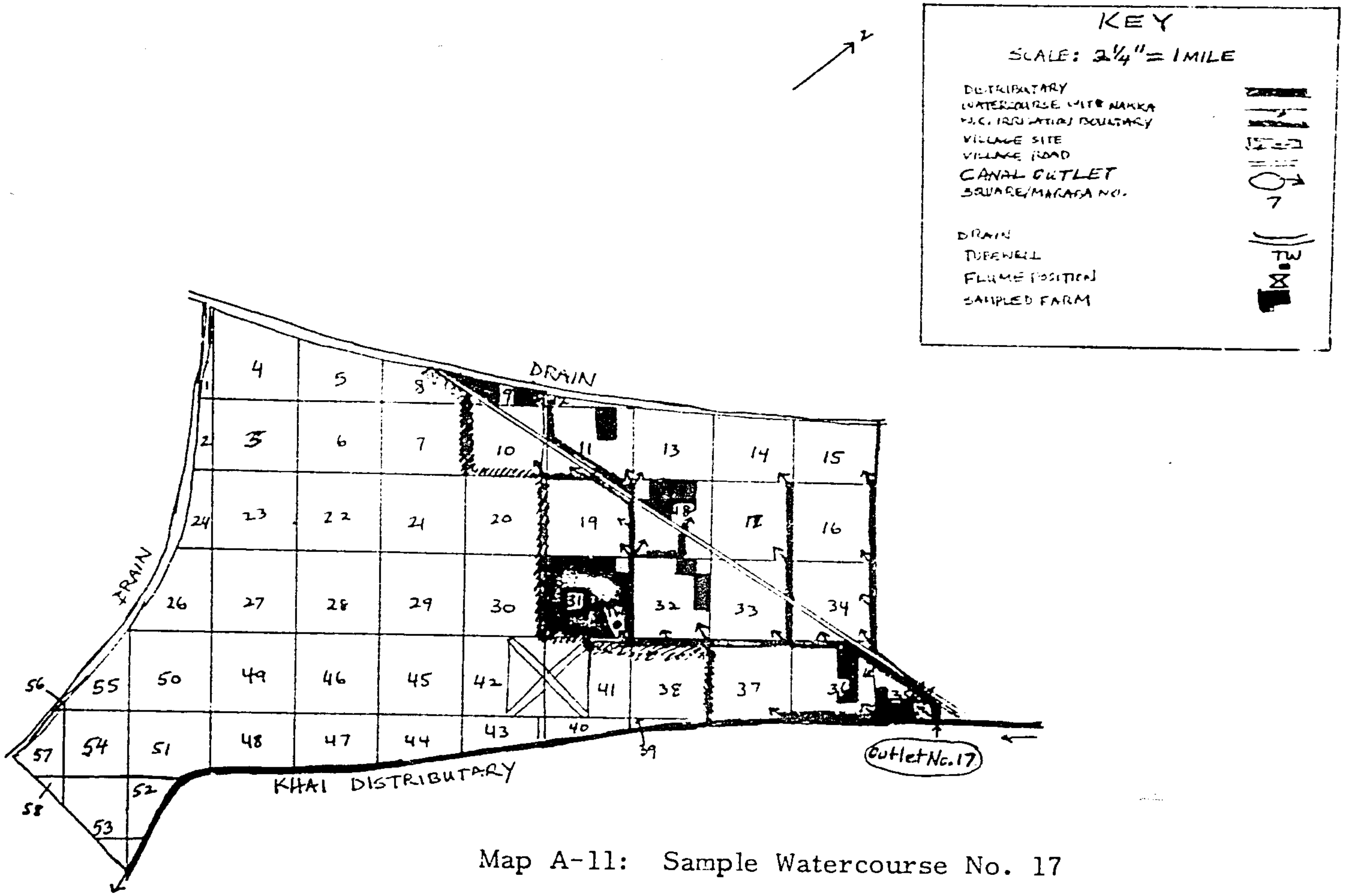
Map A-8: Sample Watercourse No.'s 11, 12



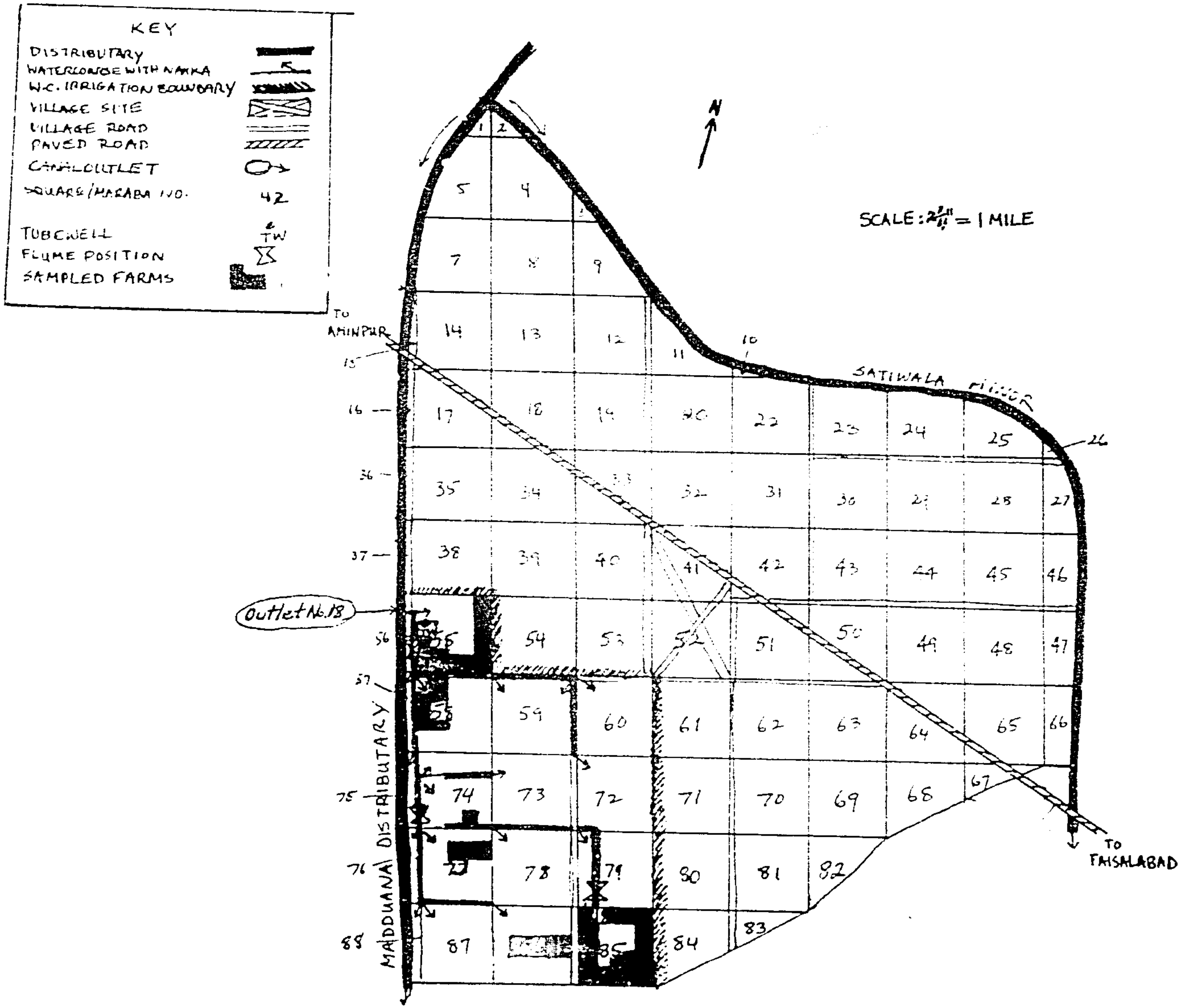
Map A-9: Sample Watercourse No. 13



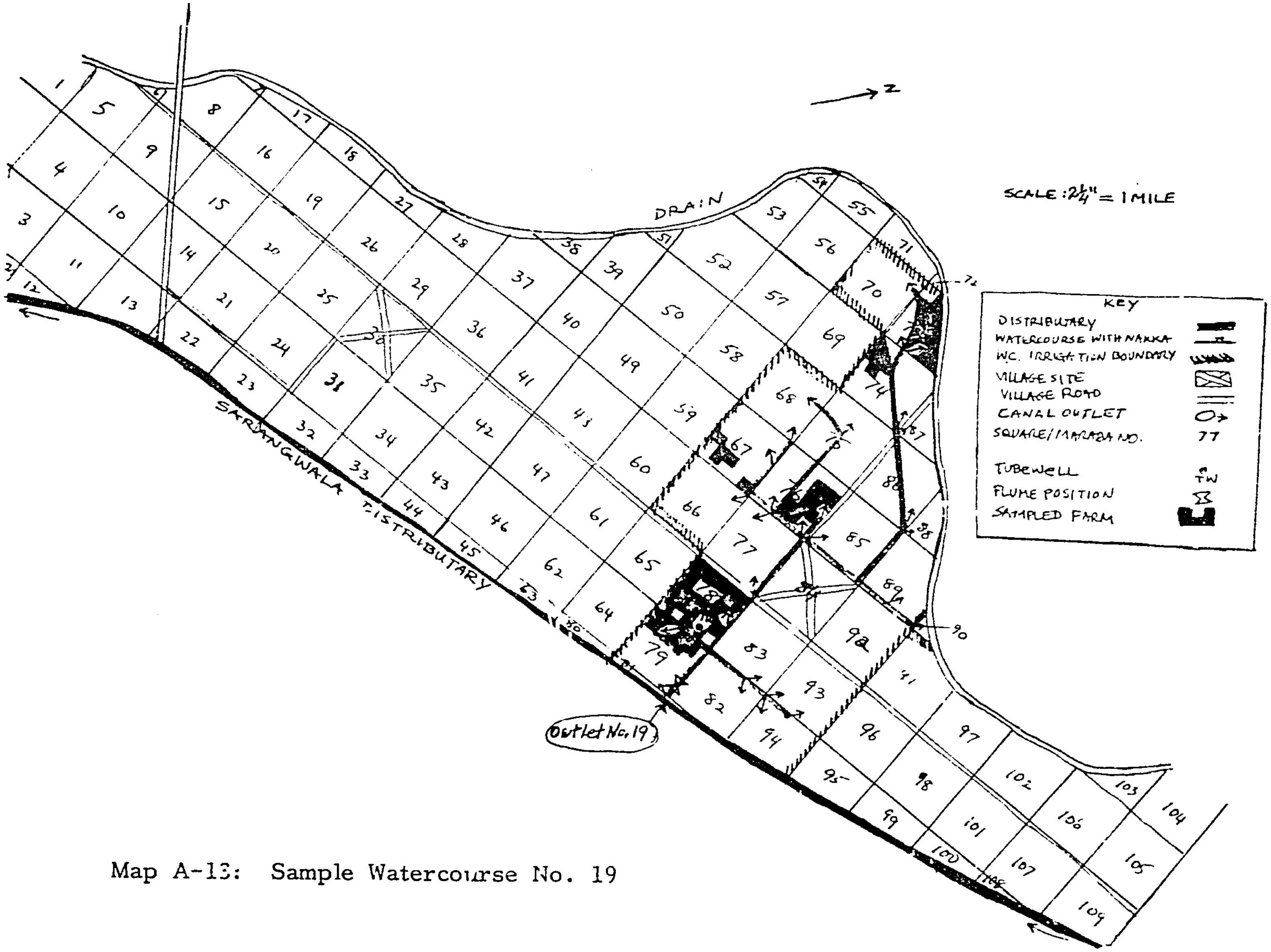
Map A-10: Sample Watercourse No. 16



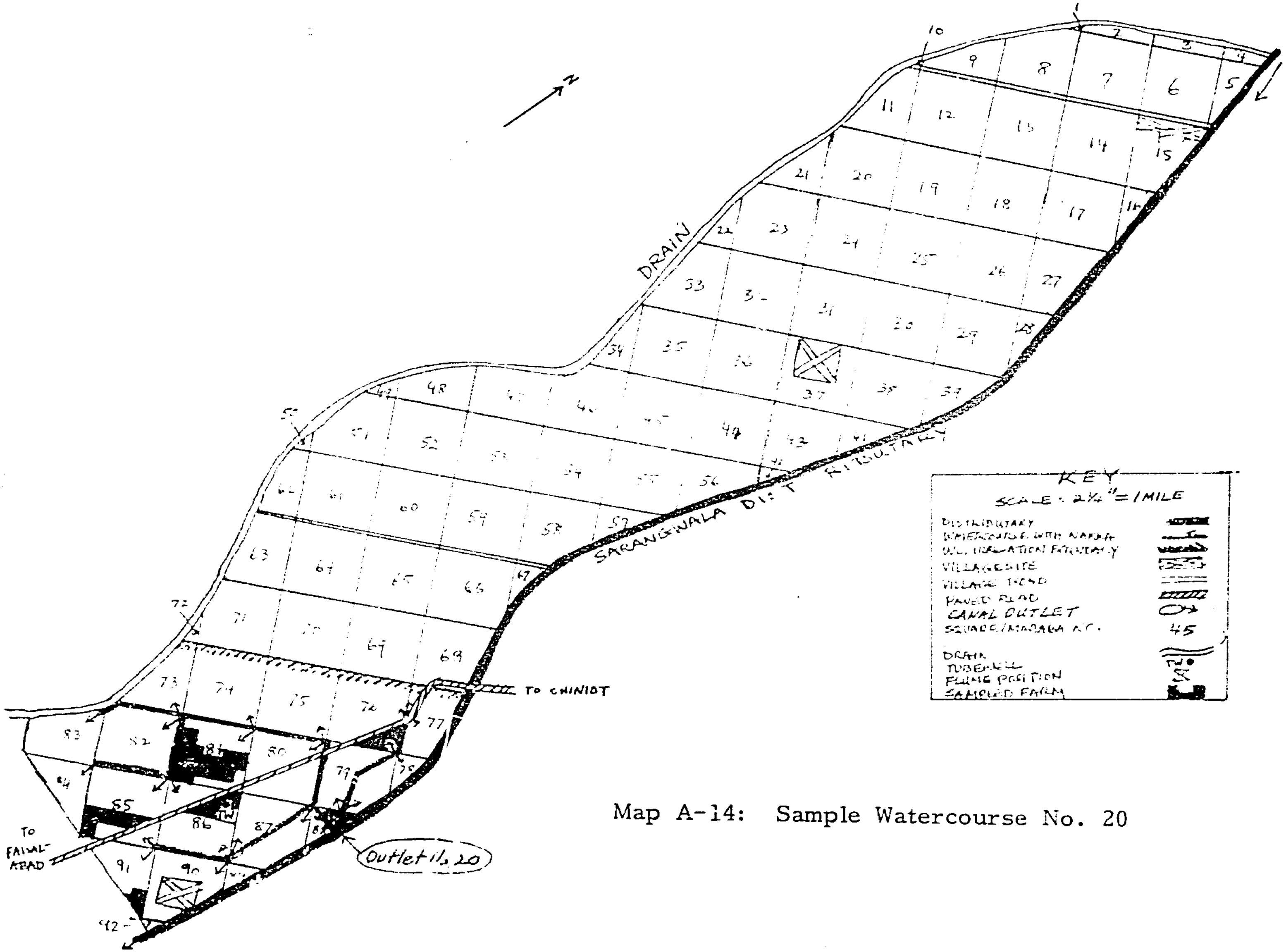
Map A-11: Sample Watercourse No. 17



Map A-12: Sample Watercourse No. 18



Map A-13: Sample Watercourse No. 19



Map A-14: Sample Watercourse No. 20

APPENDIX B

WATERCOURSE AND KEY INFORMANT(S) QUESTIONNAIRES

I. Identification

A. Sample watercourse serial No. ______

B. Subdistrict (Tehsil) ______

C. Chak No. ______

D. Village or subvillage name ______

E. Watercourse/moga No. ______

F. Canal distributary or minor name ______

G. Date of interview ______

II. Warabundi and Irrigation Water Exchange

A. Total No. of watercourses/mogas in village/subvillage ______

1. No. of unimproved ______
2. No. of partially lined (by OFWM) ______
3. No. of earthen improved (by OFWM) with pakka nakkas ______
4. No. of earthen improved (by OFWM) without pakka nakkas ______

B. Type of watercourse being considered in this interview (see A. above for code) ______

C. 1. Total No. of farms ______

2. Total W/C commanded acres ______
3. Total W/C length (killas) ______
   a. Main W/C length (killas) ______
   b. 1st Branch length (killas) ______
   c. 2nd Branch length (killas) ______
   d. 3rd Branch length (killas) ______
   e. 4th Branch length (killas) ______
   f. 5th Branch length (killas) ______
   g. 6th Branch length (killas) ______
4. Start of Warabundi, 1981: Mon. 6 ______

D. 1. Dates earthen improvements begun and completed

____

2. Dates partial lining begun and completed ____________

3. Length of lined section, if any (killas) ____________

E. Water Transactions

1. Do farmers on this water course trade canal water for canal water (warabundi time for warabundi time)? ______

CODE: 1. Yes 2. No.

2. If yes, who in general do farmers trade with? ________

CODE: 0. Not applicable 1. Relatives within maraba 2. Neighbors within maraba 3. Relatives outside, but nearby, maraba 4. Neighbors outside, but nearby, maraba 5. Relatives distant from maraba 6. Others distant from maraba

a. When do trades generally occur? __________________

CODE: 0. Not applicable 1. May/June 2. Oct/Nov/Dec 3. March/April 4. Aug/Sept 5. Other (specify) ______________________

b. What are the usual time limits (maximum and minimum minutes and/or hours) on trading?

1. May/June ________
2. Oct/Nov/Dec ________
3. March/April ________
4. Other months ________
5. Relatives within maraba ________
6. Neighbors within maraba ________
7. Neighbors outside, but nearby, maraba ________
8. Relatives, other than neighbors, but nearby maraba ________
9. Relatives distant from maraba ________
10. Others far from maraba ________

c. Do larger farmers trade relatively more or less than smaller farmers? ______________

CODE: 0. Not applicable 1. Very much more 2. Somewhat more 3. Very much less 4. Somewhat less 5. About the same

3. In general, what constraints are present which prevent or limit trading? ______________________________

CODE: 0. Not applicable 1. Length of watercourse 2. Sequence of wara — noncooperation of intermediate/neighboring farmers 3. Slope of watercourse

4. Location of trading parties on different branches 5. Will not trade outside family 6. Will not trade outside biraderi 7. Others refuse to trade with me 8. Full wara needed each week — no spare water to trade (wishes to trade but is unable) 9. No need to trade — enough water received through warabundi each and every week (not willing to trade) 10. Excessive absorption (seepage) losses in moving water and filling.

4. Do farmers owning tubewells on this watercourse sell W water? ____________

CODE: 1. Yes 2. No

5. If yes, who in general do TW owners sell to? ____________

CODE: 0. Not applicable 1. Everyone on the watercourse 2. Relatives within maraba 3. Neighbors within maraba 4. Relatives outside, but nearby, maraba 5. Neighbors outside, but nearby, maraba 6. Relatives distant from maraba 7. Others far from maraba 8. Farmers on adjacent/nearby watercourses 9. Other (specify) ____________

a. When do TW sales generally occur? ____________

CODE: 0. Not applicable 1. May/June 2. Oct/Nov/Dec 3. March/April 4. Other (specify) ____________

6. Tubewells on watercourse

S.No.	Single(S)/ Joint(J) Ownership	Name(s) of Owner(s)	Electric (E) or Diesel (D)	Pipe Size (inches)	Price/hr. when sold (Rs.)

7. Names of any farmers on the watercourse who sell canal water ____________

a. Price of canal water, if and when sold (Rs. per hour)

____

8. Do farmers on this watercourse exchange canal water for tubewell water? ____________

CODE: 1. Yes 2. No

9. If yes, names of TW owners who engage in such trades:

____

a. What is the rate of exchange of canal water for tubewell water? ____________

CODE: 0. Not applicable 1. 1 hr. CW for 1 hr. TW 2. 1 hr. CW for 1.5 hrs. TW 3. 1 hr. CW for 2 hrs. TW 4. Other (specify) ____________

b. When do such exchanges generally occur? ____________

CODE: 0. Not applicable 1. May/June 2. Oct/Nov/Dec 3. March/April 4. Other (specify) ____________

F. Measured/Actual moga discharge (cusecs/c.f.s.) ____________

G. Year decision was made to switch from katcha to pakka warabundi ____________

H. Reason(s) for switching from katcha to pakka warabundi

____

CODE: 0. Not applicable 1. Small/weak farmers were at a disadvantage 2. Head farmers were benefitting at the expense of other (middle and tail) farmers 3. Excessive water theft 4. Too many nakkas present with excessive water losses 5. Other (specify) ____________

I. Authorized bharai time (min. per killa) ____________

J. Authorized nikal time (min. per killa) ____________

K. If present, name and salary per year of khal chowkidar (timekeeper) employed on this watercourse ____________

L. Comments on the overall effectiveness of the Warabundi on this watercourse, or the Warabundi system in general, in equitably allocating water (wara times) to farmers:

1. Length of wara with respect to acreage:
2. Length of sarkari khal and No. of nakkas:
3. Additional bharai time:
4. Nikal time for farmers other than last farmer(s):
5. Additional compensation time according to length of watercourse being cleaned:
6. Additional compensation time for seepage losses:
7. Alternate ordering ofwaras for right and left farmers, whose nakkas are opposite each other on the sarkari khal:

III. Organization of Watercourse Cleaning and Maintenance

A. Common method of cleaning and maintenance ____________

CODE: 0. N/A, no program 1. Everyone cleans the entire watercourse, with branches 2. Each farmer cleans the watercourse with other farmers, but cleans only from the moga (or first nakka) to the location of his own (sarkari) nakka 3. Each farmer is responsible for cleaning his own 'reach' only (the distance from where the water is taken over from the nearest upstream farmer to where the water is given/turned over to the next downstream farmer), but cleans 'common,' head reach collectively with other farmers.

B. Frequency of cleaning per season, with approximate dates:

1. Kharif 1980 ____________ 2. Rabi 1980-81 ____________

C. Approximate time (in hours) needed to clean the sarkari khal each time:

1. Main watercourse ________ 2. Branches (each separately) ____________________

D. Approximate No. of persons who clean the sarkari khal each time:

1. Main watercourse ________ 2. Branches (each separately) ____________________

E. No. of persons not participating in each cleaning program:

	Kharif 1980	Rabi 1980-81
Main watercourse		
Branches (each separately)		

F. Sanctions for non-compliance in cleaning program(s):

1. Lose warabundi turn (indicate whether partial or complete turn, and time, (hrs./min.) lost) ____________________
2. Pay fine (Rs. amt.) ____________________
3. Pay fine in kind (amt.) ____________________
4. Social/moral persuasion (1. Yes 2. No) ____________

G. What is done with fines (money, water, goods)? ____________

H. How are penalties enforced, and by whom? ____________

I. Comments on the overall effectiveness of the cleaning program(s) in reducing water losses:

1. Method of cleaning:
2. Frequency of cleaning:
3. Sanctions for non-compliance:
4. Removal of bushes and trees:
5. Elimination of rat holes:
6. Reward (Inam) in the form of extra water for added labor and time for cleaning:
7. Other (specify):

IV. Collectice Projects

Give details of any collective projects undertaken along the watercourse (sarkari khal), within a square/maraba (internal or link watercourse), or between farmers belonging to different (extended) families, within the last five years—e.g., W/C improvement, building and/or maintaining a mosque, installing a joint tubewell, installing electricity, building and/or maintaining roads, installing drainage system, joint purchase of inputs (such as fertilizer, seed and pesticides), etc.

Project Details	Project 1	Project 2	Project 3	Project 4
1. Name of Project				
2. Duration, with dates				
3. Initiators (names)				
4. Overall degree of success				

V. Disputes/Grievances

Give details of all disputes with respect to the allocation of water along the watercourse within the last five years—e.g., cleaning and maintenance, warabundi, timings, sequence of waras, position of nakkas, illegal/unauthorized nakkas on the sarkari khal, water theft, bharai times, nikal times, refusal to sell tubewell water, refusal to cooperate in water trades, refusal to turn water over to next downstream farmer, etc.

Details of Dispute	Dispute 1	Dispute 2	Dispute 3	Dispute 4
1. Nature of dispute				
2. No. of farmers involved				
3. When it occurred (dates)				
4. Nature of settlement or compromise				

VI. Institutional Services and Active Organizations Present in Village

A. Institutional services present in village, or within a half mile (check if present)

1. Pakka road ☐
2. Railway station/bus-stop ☐
3. Post office ☐
4. Fertilizer agency ☐
5. Field Assistant ☐
6. Mandi - grain or livestock market ☐
7. Boys' school - primary ☐
   - middle ☐
   - high ☐

8. Girls' school - primary ☐
   - middle ☐
   - high ☐
9. Govt. medical dispensary ☐
10. Veterinary dispensary ☐
11. Bank branch ☐
12. Electricity ☐
13. TOTAL ☐

B. Active organizations in the village (check if present)

1. Mosque committee ☐
2. Zakat committee ☐
3. Islahi (amendment) committee ☐
4. Panchayat ☐
5. Cooperative society (bank) ☐
6. Cooperative society (for agric. inputs) ☐
7. Union Council office ☐
8. Water User Association ☐
9. Khal (watercourse) chowkidar ☐
10. Other (specify) ☐
11. TOTAL ☐

VII. Subjective Scoring of Quality of Watercourse Maintenance

The total score of quality of maintenance on the watercourse is determined by adding all observations after re-categorization and by relative position of head one-fourth, middle, one half, and tail one-fourth as indicated below. The lower the score, the better the quality of maintenance. Circle or fill-in the appropriate score for each row and total the scores.

Aspect of Watercourse	Scores/Counts if re-categorized	Scores from Observation
1. Lined section, if silted (or Head section, if silted)	(improved watercourse) (unimproved watercourse)	No = 0 Yes = 1
2. Pakka structures (pakka nakkas, culverts, buffalo-wallows, silt trap)	Actual counts of cracked = 1 (score 1) broken = 2 (score 2)	0 = 0 1 - 5 = 1 6 - 10 = 2 11 - 15 = 3 16 - 20 = 4 21 - 25 = 5 Above 25 = 7

Aspect of Watercourse	Scores/Counts if re-categorized	Scores from Observation
3. Illegal/unauthorized nakkas	Actual counts of illegal nakkas for irrigation on field only = 1 (score 1) illegal nakkas for supplying water to internal W/C = 2 (score 2)	0 = 0 1 - 10 = 1 11 - 20 = 2 21 - 30 = 3 31 - 40 = 4 41 - 50 = 5 51 - 60 = 6 Above 60 = 8
4. Weak or broken banks, cracked floors	Observed for Head, Middle and Tail Positions, then added	Head None = 0 Few = 1 Many = 2 Middle None = 0 Few = 1 Many = 2 Tail None = 0 Few = 1 Many = 2 Total
5. Rat holes and other animal dens or burrows	Observed for Head, Middle and Tail Positions, then added	Head None = 0 Few = 1 Many = 2 Middle None = 0 Few = 1 Many = 2 Tail None = 0 Few = 1 Many = 2 Total
6. Vegetation (bushes, grass and newer/smaller trees)	Observed for Head, Middle and Tail Positions, then added	Head Very little/none = 0 Little = 1 Excessive = 2 Middle 0 1 2 Tail Very little/none = 0 Little = 1 Excessive = 2 Total
7. Trees, older/larger	Actual counts	0 = 0 1 - 25 = 1 26 - 50 = 2 51 - 75 = 3 76 - 100 = 4 Above 100 = 6
8. TOTAL SCORE		

INDIVIDUAL FARMER QUESTIONNAIRE

I. IDENTIFICATION

A. Individual farmer serial No. ________

B. Individual farmer classification ________
CODE: 1. First farmer 2. Other head farmer 3. Tubewell owner 4. Middle farmer 5. Other tail farmer 6. Last farmer

C. Sample watercourse/moga No. ________ Chak No. ________

D. Interviewer's name ________ date ________

E. Farmer's name ________ Father's name ________

F. Education ________
CODE: 0. None 1. Quran Majeed only 2. Primary 3. Middle 4. Matric 5. F.A. 6. B.A. 7. Other (specify) ________

G. Actual years of formal education ________

H. Biraderi (Quam)/Caste (Zat)

I. Origin ________
CODE: 1. Local 2. Settler 3. Refugee

II. FARM AND WATERCOURSE DATA

A. Area owned (in acres)

1. This watercourse only ________
2. This village ________
3. Total (all locations) ________

B. Area cultivated (physical farm or parcel size), this watercourse only (in acres) [see pages 6 and 7 for cropped area]

1. Owner ________
2. Rented in ________
3. Rented out ________
4. Total ________
5. No. of parcels of cultivated land on this W/C, with details of [circle parcel being considered here] acreage of each ________ ________
6. Maraba No.(s) of land cultivated on this W/C ________
7. Waste land (acres) ________

8. If total cropped acres are less than acres cultivated (this W/C only), for either season, reason why some land is lying idle (uncropped) ____________
   CODE: 0. N/A 1. Waterlogging 2. Saline 3. Land leveling 4. Insufficient water 5. Other (specify) ____________

C. If land is rented in, rent paid per year (in Rs. or kind

____

D. If land is rented out, rent received per year (in Rs. or kind ____________

E. No. of years spent in farming on this particular watercourse ____________

F. Type of farming operation ____________
   CODE: 1. Individual farming, full-time 2. Individual farming, part-time 3. Joint farming, full time 4. Joint farming, part-time 5. Other (specify)

   ____

G. If farming part-time, type of non-farm business/occupation
   1. Years involved ____________
   2. Percent of time spent on non-farm activities ____________

H. Percentage (or Rs. amt.) of income from farm ____________
   1. Sources and amts. of other income ____________

I. Tubewell ownership
   CODE: 0. N/A 1. Owned privately 2. Owned jointly
   1. If owned jointly, names of other joint owners ____________

   ____

J. Warabundi timings	Day of Week	Hour of Day
1. When water is turned over to you (when wara starts)*		
2. When water is turned over by you (when wara ends)*		

K. Total warabundi time per week (hrs. and min.)
   1. Total authorized (sarkari) bharai time per week (hrs. and min.)** ____________
   2. Total authorized (sarkari) nikal time per week (hrs. and min.)** ____________

---

[*] Indicate if joint wara for entire maraba.

[**] If joint wara, indicate no. of times/month bharai and nikal time received.

L. Distance from your authorized nakka to the moga (acres/killas) ____________

M. Distance from your authorized nakka to the nearest upstream authorized nakka (acres/killas) ____________

N. Is authorized nakka used only by you or by other farmers also? ____________
CODE: 1. Used privately 2. Used jointly

O. If used jointly, number of other farmers sharing nakka ____________

  1. Of the farmers using this nakka jointly, in what order do you receive water (your wara)? ____________
  2. Amount of unauthorized (internal) bharai time (hrs. and min.)* ____________
  3. Amount of unauthorized (internal) nikal time (hrs. and min.)*
  4. Sketch a map of the land being irrigated from the authorized nakka(s) via internal watercourses, indicating the landholdings of joint (nakka-using) farmers:

---

[*] If joint wara, indicate no. of times/month bharai and nikal time received.

P. Actual participation in cooperative/joint cleaning and maintenance of the watercourse

Type of W/C	KHARIF 1980			RABI 1980-81		
	No. of Cleanings	No. of Times Participated	Total Time Spent (hrs)/ Cleaning	No. of Cleanings	No. of Times Participated	Total Time Spent (hrs)/ Cleaning
Main W/C & Branches (Sarkari Khal)						
Internal W/C (common property)						

Q. Amount of extra (private) time spent in cleaning and maintenance of the watercourse

Type of W/C	KHARIF 1980				RABI 1980-81			
	No. of Times Cleaned Privately	Time Spent on Pvt. Cleaning (hrs)	No. of Times Cleaned Jointly	Time Spent on Joint Cleaning (hrs)	No. of Times Cleaned Privately	Time Spent on Pvt. Cleaning (hrs)	No. of Times Cleaned Jointly	Time Spent on Joint Cleaning (hrs)
Main W/C and Branches (Sarkari Khal)								
Internal W/C (common property)								

III. IRRIGATION WATER SUPPLIES, APPLICATIONS AND EXCHANGE

A. Sources and Quantities of Irrigation Water Supply, with Sales and Purchases of Water for Land on this Watercourse.

Sources include canal water (CW) and tubewell water (TW). Quantities of water are measured in hrs. and min. Sales and purchases are measured both in hrs. and min. and in either rupees (Rs.) or amounts in kind.

		Kharif 1980		Rabi 1980-81	
Source of Irrigation Water	No. of Missed Waras	Hrs.	Min.	Hrs.	Min.
1. Total CW supplies from warabundi (to be converted from weekly time to seasonal time later)					
2. Plus (+) CW purchases and trading-in times					
3. Less (-) CW sales and trading-out times					
4. No. of full and partial waras traded					
5. Net CW supply (1+2+3)					
6. Total pumping time from own TW for own land					
a. TW pipe size (inches)					
7. Pumping time for TW sales					
a. No. of buyers (people sold to)					
8. Plus (+) TW purchases					
a. Names of sellers (persons bought from					

B. What are the constraints present which discourage sales or purchases of TW water? ________________

CODE: 0. N/A 1. Needs all the TW water for own uses - no spare pumping time 2. Spare pumping time exists, but strain on motor/engine precludes selling 3. Diesel fuel unavailable 4. Slope of W/C precludes selling upstream 5. Selling (buying) price prevalent in village is too low (high) 6. No one or no others wish to purchase TW water 7. Will not sell to enemies 8. Can only buy TW during own (CW) wara 9. Electricity failure 10. TW closed for repairs 11. Other (specify) ________________

C. Nature and Extent of Water Trading

1. Do you trade canal water for canal water (warabundi time for warabundi time? ______________
   CODE: 1. Yes 2. No

2. If yes, No. of farmers traded with. ______________
   a. Also if yes, who (in specific) are they? ________
      CODE: 0, N/A 1. Relatives within maraba 2. Neighbors within maraba 3. Relatives outside, but nearby, maraba 4. Neighbors outside, but nearby, maraba 5. Relatives far from maraba 6. Others far from maraba
   b. When do trades generally occur? ______________
      CODE: 0. N/A 1. May/June 2. Oct/Nov/Dec. 3. March/April 4. August/September 5. Other (specify) ______________
   c. What are the usual time limits (maximum and minimum hrs.) on trading?

Persons Traded With	May/Jun	Oct/Nov/Dec	Mar/Apr	Other Months
Relates within maraba				
Neighbors within maraba				
Relatives outside, but nearby, maraba				
Neighbors outside, but nearby, maraba				
Relatives distant from maraba				
Others distant from maraba				

3. Constraints present which prevent or limit further trading. ______________
   CODE: 0. N/A 1. Length of watercourse 2. Sequence of ware - noncooperation of intermediate/neighboring farmers 3. Slope of watercourse 4. Location of trading parties on different branches 5. Will not trade outside family 6. Will not trade outside biraderi 7. Others refuse to trade with me 8. Full wara needed each week - no spare water to trade (wishes to trade but is unable to do so) 9. No need to trade - enough water received through warabundi each and every week (not willing to trade) 10. Different length of wara (size of farm) 11. Other (specify) ______________

4. Do you ever buy or sell canal water? ______________
   CODE: 0. N/A - neither buy nor sell CW
   1. Buy CW 2. Sell CW

   a. Price of CW, if and when bought or sold (Rs./hr.)

   ____

   b. If bought or sold, names of persons bought from or sold to ______________________________

   c. Year and season CW was bought or sold ____________

5. Do you ever trade canal water for tubewell water (or vice versa)? ______________________________
   CODE: 1. Yes 2. No.

6. If yes, names of farmers traded with, and relation (i.e., relative, friend, neighbor, etc.) ____________________

   a. When do trades generally occur? ____________________
   CODE: 0. N/A 1. May/June 2. Oct/Nov/Dec 3. March/April 4. Other (specify) ____________

   b. Rate of exchange of canal water for tubewell water
   CODE: 0. N/A 1. 1 hr. CW for 1 hr. TW 2. 1 hr. CW for 1.5 hrs. TW 3. 1 hr. CW for 2 hrs. TW 4. Other (specify) ____________________

7. What are the constraints on exchange of canal water for tubewell water? ____________________
   CODE: 0. N/A 1. CW is of better quality (less salty, contains silt) than TW 2. No spare TW for exchange 3. Length of watercourse 4. Slope of W/C 5. Location of trading parties on different branches 6. No spare CW for exchange 7. No need to trade 8. Other (specify) ______________________________

D. Irrigation Applications by Source of Water, Crop and Season for Land on this W/C only

Major Crops by Season	Area Planted			CW Applications						TW Applications						CW+TW Applications					
				Heavy			Light			Heavy			Light			Heavy			Light		
				Total No. of	Time/Acre		Total No. of	Time/Acre		Total No. of	Time/Acre		Total No. of	Time/Acre		Total No. of	Time/Acre		Total No. of	Time/Acre	
	Acres	Kanals	Marlas	Appl.	Hrs.	Min.	Appl.	Hrs.	Min.	Appl.	Hrs.	Min.	Appl.	Hrs.	Min.	Appl.	Hrs.	Min.	Appl.	Hrs.	Min.
1. Sugarcane (full year crop)																					
2. Maize Grain																					
3. Rice																					
4. Fodder																					
5. Cotton																					
6. Orchard																					
7. Tobacco																					
8. Vegetables																					
9. TOTAL KHARIF 80																					
1. Wheat																					
2. Fodder																					
3. Orchard																					
4. Vegetables																					
5. TOTAL RABI 80-81																					

IV. FARM PRODUCTION, SALES AND INPUT COST DATA

A. Cropping Patterns, Production, Sales, Prices and Inputs of Seed, Fertilizer and Pesticides

Major Crops by Season	Area Planted A K M	Production (maunds)	Amt. Sold (maunds)	Price Sold (Rs/md)	PURCHASED HYV SEEDS		FERTILIZER									PESTICIDE
							Urea(N)		Nitrophos (N+P)		DAP(N+P)		Other		FYM	
					Units* (No.)	Price/ Unit (Rs)	No. of Bags	Rs/ Bag	No. of Bags	Rs/ Bag	No. of Bags	Rs/ Bag	No. of Bags	Rs/ Bag	Cartloads (25-30md)	Total Exp. (Rs.)
1. Sugarcane (full year crop)																
2. Maize Grain																
3. Rice																
4. Fodder																
5. Cotton																
6. Orchard																
7. Tobacco																
8. Vegetables																
9. TOTAL KHARIF 80																
1. Wheat																
2. Fodder																
3. Orchard																
4. Vegetables																
5. TOTAL RABI 80-81																

B. Labor

1. No. of family members ______
    a. Adults engaged in full-time farming activities ______
    b. Adults engagedin part-time farming activities ______
    c. Minors engaged in full-time farming activities ______
    d. Minors engaged in part-time farming activities ______

2. Permanent Labor

Season	ADULTS					MINORS				
	No. Hired	Duties	Wage			No. Hired	Duties	Wage		
			Rs.	Mds.	Clothes			Rs.	Mds.	Clothes
1. Kharif 1980										
2. Rabi 1980-81										

C. Tractor and Thresher Ownership

Season	Diesel used (drums* or liters)	Price/drum* or liter (Rs.)	Income from rental (Rs.)
1. Kharif 1980			
2. Rabi 1980-81			

*1 Drum - 48 gal.

	Tractor	Thresher
Year Purchased		
Initial Cost (Rs.)		

D. No. of bullocks owned, and used for field work:

1. KHARIF 1980 ______
2. RABI 1980-81 ______

F. Casual Hired Labor, Tractor Rental and Bullock Rental Inputs Per Cropping Activity

		Casual Hired Labor					Hired Tractor/Thresher Operations		Hired Bullocks Operations	
				Wage/Day/Person						
Crop	Activity	No.	Days	Rs.	Kind	Amt.	No. Oper.	Rent/Oper. (Rs.)	No. Oper.	Rent/Oper. (Rs.)
1. Sugarcane	Plowing									
	Planking									
	Planting/sowing									
	Hoeing									
	Spraying/dusting									
	Cutting/stripping/loading									
2. Maize Grain	Plowing									
	Planking									
	Hoeing									
	Harvesting									
3. Rice	Plowing									
	Transplanting									
	Harvesting/threshing									
4. Fodder	Plowing									
	Planking									
	Harvesting/loading									
5. Cotton	Plowing									
	Planking									
	Picking									
6. Tobacco	Processing									
7. Vegetables	Seedbed preparation									
	Hoeing									
	Picking/loading									
8. TOTAL KHARIF 1980										
1. Wheat	Plowing									
	Planking									
	Harvesting									
	Threshing									
2. Fodder	Plowing									
	Planking									
	Harvesting/loading									
3. Vegetables	Seedbed preparation									
	Hoeing									
	Picking/loading									
4. TOTAL RABI 1980-81										

F. Tubewell Ownership (only to be asked of actual tubewell owners)

1. Year tubewell(s) purchased ______
2. Initial Costs
    a. Material costs (Rs.) ______
    b. Transportation costs (Rs.) ______
    c. Casual hired labor costs (Rs.) ______
    d. Total cost (Rs.) ______
3. Seasonal Pumping/Running Costs
    a. Electrical Tubewell
        1. KHARIF 1980 (total cost in Rs.) ______
        2. RABI 1980-81 (total cost in Rs.) ______
    b. Diesel Tubewell

Season	No.Gal	Rs/Gal.	Amt. (1x2) (Rs.)	No.of Drums (48 gal.)	Rs/Drum
1. KHARIF 1980					
2. RABI 1980-81					

Season	Other Costs (Lubricants) (Rs.)	TOTAL COST (3+7) or (6+7) (Rs.)
1. KHARIF 1980		
2. RABI 1980-81		

APPENDIX C

CONTRASTS BETWEEN METHODS OF ESTIMATING IRRIGATION WATER SUPPLIES

Largely by accident, it was discovered that estimates of farmer water supplies using actual water flow measurements were significantly different from estimates using a rule of thumb widely applied in production related irrigation studies.

The method used in this thesis for estimation of canal water supplies received by sampled farmers in the 1980-81 crop year was to discount canal outlet discharge by a loss rate function estimated through actual flow measurements using cut-throat flumes. Measured canal outlet discharge discounted by cumulative losses to the farmer's field outlet (nakka) provides an average acre inch per hour volume received at the farm.

Based largely on the results of Trout and Bowers (1979) losses incurred on internal watercourses were assumed to be equal to losses incurred on main watercourse channels. Also, it was assumed that canal water flows were constant throughout the 1980-81 crop year, and that flow measurements taken in early September 1981 were representative of flows throughout the summer 1980 and winter 1980-81 cropping seasons. With these assumptions, the average per acre volume estimates for each farm are then multiplied by the length of turn (in hours) received each week through pakka warabundi, and by the number of turns actually received in 1980-81 to yield the total acre inches of canal water received per sampled farm.

Estimates of the volume of tubewell water received are also calculated in this fashion. However, for those farmers who most frequently mix tubewell water with canal water (i.e., irrigate with tubewell water during times of canal water turn) per acre losses are assumed to be 25% less, due to the fact that tubewell water losses are not typically incurred for these irrigators in wetting a dry perimeter but only in conveying water in a wetted perimeter. Volumes of tubewell water received are calculated as the product of measured tubewell discharge (in acre inch hours), the per acre loss rate, the distance of the farm from the tubewell (in acre units) and the number of hours of tubewell water used in 1980-81.

The conventional method of estimating irrigation water supplies, used by many social scientists, agronomists and engineers alike, is to elicit individual farmer responses on the number of "heavy" and "light" irrigations applied to crops per farm or parcel and the number of hours of water applied per heavy and light irrigation. A common assumption is then made that a heavy irrigation is equivalent to four acre inch hours, and a light irrigation is equal to two and a half acre inch hours. Volumes of water applied are then calculated, for inclusion in production function or other types of analyses.

Data required for both types of estimates were collected in the survey, therefore comparisons could be made between the measured volumetric method and volumetric estimates using the conventional 2½-4 acre inch assumption. From 129 individual responses, the mean per acre volume of irrigation water (both canal and tubewell water) applied using the 2½-4 acre inch assumption is 71.9 acre inches. The estimated mean per acre volume of irrigation water applied for the same 129 farmers using the flume-loss rate function method, on the other hand, is 33.9 acre inches. Per acre volumes estimated through the 2½-4 acre inch method are 115% higher than measured per acre volumes, and the difference is highly significant at the 0.1% level (the 99.9% student's t confidence interval is 38 ± 11). Therefore, we conclude that the conventional method tends to overestimate measured water supplies received and applied of the order of 115%.

This overestimation is not so much due to an exaggeration of the total hours of canal and tubewell water applied, as compared to the hours actually received through warabundi and tubewell use,[15] but because of water conveyance losses in the watercourses. More accurate estimation of volumes received and applied, in the absence of actual volume measurements, would be achieved in the context of earthen watercourse irrigation of the Pakistan form by a downward revision of the acre inch assumptions of heavy and light irrigations of the order of 115% <u>for all farmers</u>, irrespective of location relative to the canal outlet or in the watercourse commanded area.

If more accurate estimation is desired with respect to sampled farmers at head, middle and tail locations, the results from this research indicate that the per acre volume (acre-inch) estimates should be revised downwards by 53% for head irrigators, 51% for

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[15] In fact, the mean number of hours (158) reported applied by farmers was less than the mean number of hours actually received through warabundi and tubewell use (190). The percentage difference between the two means is 20%; but construction of a 95% confidence interval to test this difference implies an acceptance of H_0, that the difference in means is not significantly different from zero. The 95% confidence interval is 32 ± 42.

middle irrigators and 40% for tail irrigators.[16] In other words, for head farmers, a light irrigation should more accurately be defined as 1.32 acre inches and a heavy irrigation as 2.12 acre inches. For middle farmers a light irrigation can be defined as 1.28 acre inches and a heavy irrigation as 2.04 acre inches. For tail farmers a light irrigation can be defined as 1.01 acre inches and a heavy irrigation as 1.62 acre inches.

---

[16] The mean acre inch per acre values for head farmers, n=47, using the 2½-4 acre inch estimation and the flume-loss rate function method are 75.89 and 40.15, respectively. For middle farmers, n=43, the respective mean values are 68.27 and 35.08. For tail farmers, n=38, the respective mean values are 70.01 and 28.32.

APPENDIX D

TABULAR RESULTS FROM ANALYSIS OF VARIANCE (ANOVA) RELATING GROSS INCOME PER ACRE TO CATEGORIES OF:

1. Singly-owned tubewell water using farms, joint property tubewell water using farms and no tubewell water using farms;

2. Active trading farms, inactive trading farms and no trading farms;

3. Kachha internal warabundi practicing farms and pakka internal warabundi practicing farms;

4. Farms on improved watercourses and farms on unimproved (control) watercourses; and

5. Farms on watercourses with two or more collective projects and farms on watercourses with zero or one collective project.

Table D-1. Mean Gross Income per Acre for Categories of Tubewell Water Use, Trading, Type of Internal Warabundi, Type of Watercourse, No. of Collective Projects and the Total Sample.

Major Category	Sub-Category	Mean Gross Income per Acre	No. of Observations
Type of Tubewell Water Use	Singly Owned	4019	32
	Joint Property	3157	28
	None	3018	69
Nature of Trading	Active	3828	42
	Inactive	3048	71
	None	3007	16
Type of Internal Warabundi	Kachha	3343	77
	Pakka	3228	52
Type of Watercourse	Improved	3482	65
	Unimproved	3108	64
No. of Collective Projects	2+	3441	53
	0 or 1	3196	76
Total Sample		3297	129

Table D-2. Two-Way Table of Mean Gross Income per Acre and No. of Observations (in parentheses) for Categories of Tubewell Using Farms and (a) Trading Farms; (b) Type of Internal Warabundi Practiced; (c) Type of Watercourse; and (d) No. of Collective Projects.

		Type of Tubewell Water Use		
		Singly Owned	Joint Property	None
(a) Two-Way: Tubewell Water Use and Trading				
Degree of Trading	Active	4919 (16)	3769 (9)	3027 (19)
	Inactive	3351 (12)	2966 (13)	2915 (44)
	None	2425 (4)	2656 (6)	3748 (6)
(b) Two-Way: Tubewell Water Use and Type of Internal Warabundi				
Type of Internal Warabundi	Kachha	4000 (22)	3345 (22)	2905 (33)
	Pakka	4062 (10)	2471 (6)	3123 (36)
(c) Two-Way: Tubewell Water Use and Type of Watercourse				
Type of Watercourse	Improved	3995 (18)	3317 (21)	3261 (26)
	Unimproved	4050 (14)	2678 (7)	2872 (43)
(d) Two-Way: Tubewell Water Use and No. of Collective Projects				
No. of Collective Projects	2+	4087 (18)	3482 (18)	2715 (17)
	0 or 1	3932 (14)	2572 (10)	3118 (52)

Table D-3. Two-Way Table of Mean Gross Income per Acre and No. of Observations (in parentheses) for Categories of Trading Farms and (a) Type of Internal Warabundi Practiced; (b) Type of Watercourse; and (c) No. of Collective Projects.

		Degree of Trading		
		Active	Inactive	None
(a) Two-Way: Trading and Type of Internal Warabundi				
Type of Internal Warabundi	Kachha	3808 (30)	3029 (43)	3273 (4)
	Pakka	3992 (14)	2954 (26)	2931 (12)
(b) Two-Way: Trading and Type of Watercourse				
Type of Watercourse	Improved	3901 (29)	3098 (27)	3287 (9)
	Unimproved	3801 (15)	2938 (42)	2647 (7)
(c) Two-Way: Trading and No. of Collective Projects				
No. of Collective Projects	2+	4020 (21)	3123 (24)	2876 (8)
	0 or 1	3726 (23)	2935 (45)	3140 (8)

Table D-4. Two-Way Table of Mean Gross Income per Acre and No. of Observations (in parentheses) for Categories of Type of Internal Warabundi Practiced and (a) Type of Watercourse; and (b) No. of Collective Projects.

		Type of Internal Warabundi	
		Kachha	Pakka
(a) Two-Way: Type of Internal Warabundi and Type of Watercourse			
Type of Watercourse	Improved	3512 (42)	3428 (23)
	Unimproved	3141 (35)	3069 (29)
(b) Two-Way: Type of Internal Warabundi and No. of Collective Projects			
No. of Collective Projects	2+	3453 (42)	3211 (35)
	0 or 1	3396 (11)	3183 (41)

Table D-5. Two-Way Table of Mean Gross Income per Acre and No. of Observations (in parentheses) for Categories of Type of Watercourse and No. of Collective Projects.

		Type of Watercourse	
		Improved	Unimproved
No. of Collective Projects	2+	3490 (40)	3292 (13)
	0 or 1	3471 (25)	3061 (51)

Table D-6. Three-Way Table of Mean Gross Income per Acre and No. of Observations (in parentheses) for Categories of Tubewell Water Using Farms and Type of Internal Warabundi Practiced and (a) Trading; (b) Type Watercourse; and (c) No. of Collective Projects.

		Type of Tubewell Water Use					
		Singly Owned		Jointly Owned		None	
		Kachha Int.Warab.	Pakka Int.Warab.	Kachha Int.Warab.	Pakka Int.Warab.	Kachha Int.Warab.	Pakka Int.Warab.
(a) Three-Way: Tubewell Water Use, Type of Internal Warabundi Practiced and Trading							
Degree of Trading	Active	4591 (12)	5902 (4)	3669 (8)	4564 (1)	2980 (10)	3079 (9)
	Inactive	3453 (9)	3045 (3)	3114 (12)	1182 (1)	2809 (22)	3022 (22)
	None	1827 (1)	2625 (3)	3428 (2)	2270 (4)	4265 (1)	3644 (5)
(b) Three-Way: Tubewell Water Use, Type of Internal Warabundi and Type of Watercourse							
Type of Watercourse	Improved	3865 (15)	4648 (3)	3346 (17)	3193 (4)	3265 (10)	3259 (16)
	Unimproved	4289 (7)	3811 (7)	3339 (5)	1026 (2)	2748 (23)	3014 (20)
(c) Three-Way: Tubewell Water Use, Type of Internal Warabundi and No. of Collective Projects							
No. of Collective Projects	2+	3975 (15)	4648 (3)	3565 (14)	3193 (4)	2731 (13)	2660 (4)
	0 or 1	4054 (7)	3811 (7)	2959 (8)	1026 (2)	3017 (20)	3181 (32)

Table D-7. Three-Way Table of Mean Gross Income per Acre and No. of Observations (in parentheses) for Categories of Tubewell Water Using Farms and Type of Watercourse and (a) Trading; and (b) No. of Collective Projects.

	Type of Tubewell Water Use					
	Singly Owned		Joint Property		None	
	Improved Watercourse	Unimproved Watercourse	Improved Watercourse	Unimproved Watercourse	Improved Watercourse	Unimproved Watercourse
(a) Three-Way: Tubewell Water Use, Type of Watercourse and Trading						
Degree of Trading: Active	4603 (11)	5615 (5)	3769 (9)	0 (0)	3175 (9)	2894 (10)
Inactive	3243 (6)	3459 (6)	2954 (7)	2679 (6)	3108 (14)	2825 (30)
None	1827 (1)	2625 (3)	3013 (5)	870 (1)	4233 (3)	3263 (3)
(b) Three-Way: Tubewell Water Use, Type of Watercourse and No. of Collective Projects						
No. of Collective Projects: 2+	3958 (14)	4538 (4)	3482 (18)	0 (0)	2687 (8)	2739 (9)
0 or 1	4125 (4)	3855 (10)	2326 (3)	2678 (7)	3516 (18)	2907 (34)

Table D-8. Three-Way Table of Mean Gross Income per Acre and No. of Observations (in parentheses) for Categories of Trading Farms and No. of Collective Projects and (a) Tubewell Using Farms; (b) Type of Internal Warabundi; and (c) Type of Watercourse.

		Degree of Trading					
		Active		Inactive		None	
		2+ Coll.Proj.	0 or 1 Coll.Proj.	2+ Coll.Proj.	0 or 1 Coll.Proj.	2+ Coll.Proj.	0 or 1 Coll.Proj.
(a) Three-Way: Trading, No. of Collective Projects and Tubewell Water Use							
Type of Tubewell Water Use	Singly Owned	5022 (8)	4816 (8)	3507 (9)	2883 (3)	1827 (1)	2625 (3)
	Joint Property	4049 (8)	1527 (1)	3045 (5)	2916 (8)	3013 (5)	870 (1)
	None	2373 (5)	3260 (14)	2817 (10)	2944 (34)	3057 (2)	4094 (4)
(b) Three-Way: Trading, No. of Collective Projects and Type of Internal Warabundi							
Type of Interval Warabundi	Kachha	3884 (18)	3695 (12)	3164 (21)	2899 (22)	2894 (3)	4265 (1)
	Pakka	4842 (3)	3759 (11)	2836 (3)	2969 (23)	2864 (5)	2979 (7)
(c) Three-Way: Trading, No. of Collective Projects and Type of Watercourse							
Type of Watercourse	Improved	4077 (18)	3612 (11)	3125 (15)	3065 (12)	2761 (7)	5133 (2)
	Unimproved	3681 (3)	3831 (12)	3120 (9)	2888 (33)	3679 (1)	2476 (6)

Table D-9. Three-Way Table of Mean Gross Income per Acre and No. of Observations (in parentheses) for Categories of Type of Internal Warabundi Practiced and Type of Watercourse and (a) Trading; and (b) No. of Collective Projects.

		Type of Internal Warabundi Practiced			
		Kachha		Pakka	
		Improved Watercourse	Unimproved Watercourse	Improved Watercourse	Unimproved Watercourse
(a) Type of Internal Warabundi, Type of Watercourse and Trading					
Nature of Trading	Active	3860 (21)	3688 (9)	4008 (8)	3970 (6)
	Inactive	3147 (17)	2951 (26)	3015 (10)	2916 (16)
	None	3237 (4)	0 (0)	3328 (5)	2647 (7)
(b) Type of Internal Warabundi, Type of Watercourse and No. of Collective Projects					
No. of Collective Projects	2+	3530 (30)	3260 (12)	3368 (10)	3679 (1)
	0 or 1	3466 (12)	3078 (23)	3475 (13)	3047 (28)

Table D-10. Four-Way Table of Mean Gross Income per Acre and No. of Observations (in parentheses) for Categories of Tubewell Water Using Farms and Type of Internal Warabundi Practiced and (a) Trading and Type of Watercourses; (b) Trading and No. of Collective Projects; and (c) Type of Watercourse and No. of Collective Projects.

		Type of Tubewell Water Use					
		Singly Owned		Joint Property		None	
		Kachha Int.Warab.	Pakka Int.Warab.	Kachha Int.Warab.	Pakka Int.Warab.	Kachha Int.Warab.	Pakka Int.Warab.
(a) Tubewell Water Use, Type of Internal Warabundi, Trading and Type of Watercourse							
Active Trading	Improved Watercourse	4518 (9)	4982 (2)	3669 (8)	4564 (1)	2759 (4)	3507 (5)
	Unimproved Watercourse	4809 (3)	6823 (2)	0 (0)	0 (0)	3128 (6)	2543 (4)
Inactive Trading	Improved Watercourse	3096 (5)	3980 (1)	2954 (7)	0 (0)	3469 (5)	2908 (9)
	Unimproved Watercourse	3900 (4)	2577 (2)	3339 (5)	1182 (1)	2614 (17)	3102 (13)
None	Improved Watercourse	1827 (1)	0 (0)	3428 (2)	2736 (3)	4265 (1)	4217 (2)
	Unimproved Watercourse	0 (0)	2625 (3)	0 (0)	870 (1)	0 (0)	3263 (3)
(b) Tubewell Water Use, Type of Internal Warabundi, Trading and No. of Collective Projects							
Active Trading	2+ Coll.Proj.	5036 (6)	4982 (2)	39[illegible] (7)	4564 (1)	2373 (5)	0 (0)
	0 or 1 Coll.Proj.	4147 (6)	6823 (2)	3495 (1)	0 (0)	0 (0)	3079 (9)
Inactive Trading	2+ Coll.Proj.	3448 (8)	3980 (1)	3045 (5)	0 (0)	2955 (8)	2264 (2)
	0 or 1 Coll.Proj.	1527 (1)	2577 (2)	3164 (7)	1182 (1)	0 (0)	3098 (20)
None	2+ Coll.Proj.	1827 (1)	0 (0)	3428 (2)	2736 (3)	0 (0)	3057 (2)
	0 or 1 Coll.Proj.	3587 (5)	2625 (3)	2725 (14)	870 (1)	4265 (1)	4036 (3)
(c) Tubewell Water Use, Type of Internal Warabundi, Type of Watercourse and No. of Collective Projects							
Improved Watercourse	2+ Coll.Proj.	3770 (11)	4648 (3)	3565 (14)	3193 (4)	2907 (5)	2320 (3)
	0 or 1 Coll.Proj.	4125 (4)	0 (0)	2326 (3)	0 (0)	3622 (5)	3475 (13)
Unimproved Watercourse	2+ Coll.Proj.	4538 (4)	0 (0)	0 (0)	0 (0)	2622 (8)	3679 (1)
	0 or 1 Coll.Proj.	3958 (3)	3811 (7)	3339 (5)	1026 (2)	2816 (15)	2979 (19)

Table D-11. Four-Way Table of Mean Gross Income per Acre and No. of Observations (in parentheses) for Categories of Trading Farms and Type of Watercourse and (a) Tubewell Water Using Farms and No. of Collective Projects; and (b) Type of Internal Warabundi Practiced and No. of Collective Projects.

		Nature of Trading					
		Active		Inactive		None	
		Improved W.C.	Unimproved W.C.	Improved W.C.	Unimproved W.C.	Improved W.C.	Unimproved W.C.
(a) Trading, Type of Watercourse, Tubewell Water Use and No. of Collective Projects							
Singly Owned Tubewell Water Use	2+ Coll.Proj.	4875 (7)	6048 (1)	3243 (6)	4034 (3)	1827 (1)	0 (0)
	0 or 1 Coll.Proj.	4125 (4)	5507 (4)	0 (0)	2883 (3)	0 (0)	2625 (3)
Joint Property Tubewell Water Use	2+ Coll.Proj.	4049 (8)	0 (0)	3045 (5)	0 (0)	3013 (5)	0 (0)
	0 or 1 Coll.Proj.	1527 (1)	2726 (2)	0 (0)	0 (0)	2979 (6)	870 (1)
No Tubewell Water Use	2+ Coll.Proj.	2290 (3)	2497 (2)	3048 (4)	2663 (6)	2434 (1)	3679 (1)
	0 or 1 Coll.Proj.	3617 (6)	3132 (10)	5133 (2)	2993 (8)	2866 (24)	3055 (2)
(b) Trading, Type of Watercourse, Type of Internal Warabundi and No. of Collective Projects							
Kachha Internal Warabundi	2+ Coll.Proj.	3924 (15)	3681 (3)	3197 (12)	3120 (9)	2836 (3)	0 (0)
	0 or 1 Coll.Proj.	3699 (6)	3692 (6)	2027 (5)	3862 (17)	4265 (1)	0 (0)
Pakka Internal Warabundi	2+ Coll.Proj.	4842 (3)	0 (0)	2894 (3)	0 (0)	2661 (4)	3679 (1)
	0 or 1 Coll.Proj.	3507 (5)	3970 (6)	3092 (7)	2516 (16)	6000 (1)	2476 (6)