THE PERFORMANCE OF A LARGE FARMER-MANAGED IRRIGATION SYSTEM IN THE TERAI OF NEPAL

by

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A thesis submitted
under the supervision of
Dr. Eric Schiller

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DEDICATION

To the farmers of the Sorha Mauja
Irrigation System... may your achievements
change the minds of many.

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Due to the considerable duration and scope of this research, many persons made significant contributions to the success of this study and deserve special mention here.

Without the superhuman support of my wife Polly, this volume and the months of work that went into it would never have reached a successful conclusion. Throughout the highs and lows, this was very much a joint endeavour, and many times when the pressure pushed me to the breaking point her love and encouragement pulled me through.

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ABSTRACT

The government of Nepal and donor agencies have placed a high priority on the development of irrigated agriculture in the Terai region of Nepal in a bid to achieve secure production levels of food grains and other necessary agricultural commodities. Since Farmer-Managed Irrigation Systems (FMIS) comprise most of the irrigated area in this region, thorough evaluation of these systems must preclude further irrigation development.

The objective of this program of intensive field research was to use quantitative measurements and detailed observation over a significant period of time in order to evaluate the performance of a large farmer-managed irrigation system in the Terai region of Nepal.

Performance evaluation of an irrigation system requires consideration of a wide range of important parameters or measures. This study sought to evaluate the 1500 hectare Sorha Mauja Irrigation System (SMIS) near Butwal, Nepal, through one year of field research. Specific measures evaluated include water use efficiency, water allocation and equity, water supply adequacy, cropping intensity and crop production.

Data collected over an eight month period corresponding to the "dry season" included: climate, water supply and deliveries at all levels of the system, second and third crop season irrigations, cropping intensity, crop production and management activities.

The SMIS farmers have developed a strong and effective management organization which has sustained irrigated agriculture for over 50 years, and they are continuing to develop and implement improvements to their system. Farmers face a problem of high water conveyance and delivery losses between the source and their fields during the dry season. Management apportions water fairly according to their water allocation principles, but equity in field deliveries is distorted due to losses. Nevertheless, the water supply is adequate for irrigated cropping of all the cultivable land in the command area except during the period of February through May. Most SMIS farmers engage in a very intensive cropping sequence of up to three crops per year, with yields much higher than the national average. Resolution of the water adequacy and conveyance loss problems during the third crop period may facilitate even higher annual production.

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GLOSSARY

ADB	Asian Development Bank
ADBN	Agriculture Development Bank of Nepal
bigha	0.67 hectare, unit of land area in system under study
BLGWP	Bhairawa Lumbini Ground Water Project
chief muktiyar	irrigation manager of main canal system
CIDA	Canadian International Development Agency
CIR	crop intensity ratio
CIWEC	Canadian International Water and Energy Consultants
CMIS	Chhattis Mauja Irrigation System, currently serving 36 (chhattis) maujas
commad area (CA)	the gross area to which water can be supplied for irrigation from a given source
cumec	cubic metres per second
CWR	crop water requirements
DIHM	Department of Irrigation, Hydrology and Meteorology, Nepal
DoI	Department of Irrigation, Nepal
FIWUD	Farm Irrigation and Water Utilization Division (of MoA)
FMIS	farmer managed irrigation system
GDP	gross domestic product
GNP	gross national product
ha	hectare
HMGN	His Majesty's Government of Nepal

IIMI	International Irrigation Management Institute
khara	fines levied against farmers who are absent from kulari (maintenance) work
km	kilometre
kulahi	labour contribution requirements.
Kulara	a share system of apportioning both water supply and labour requirements.
mauja	village or branch canal area
MoA	Ministry of Agriculture, Nepal
MPLD	Ministry of Panchayat and Local Development, Nepal
muktiyar	irrigation manager of individual mauja
MWR	Ministry of Water Resources,Nepal
panchayat	local political constituency
rupee	Nepalese currency, 24 rupees = 1 Canadian dollar (1989)
SID	Small Irrigation Division, Nepal
SMIS	Sorha Mauja Irrigation System, serving 16 (sorha) maujas at it's inception, currently serving 33 maujas
Terai	low lying plains region of southern Nepal
Tharu	indigenous Terai inhabitants
WECS	Water and Energy Commission Secretariat, Nepal

CHAPTER 1

INTRODUCTION

1.1 General

Of over 200 million hectares (ha) of irrigated land in the world, three-fourths is located in 22 developing countries where 800 - 1000 million people depend directly on irrigated agriculture for their livelihoods. As these populations and developing national economies continue to grow, there are mounting pressures to intensify land and water use for the purpose of increasing and stabilizing agricultural production. To this end, considerable assistance has been delivered to developing country governments for the construction of new irrigation systems and for the rehabilitation or expansion of existing systems. The results of these efforts to enhance agricultural production through irrigation development have, however, often fallen short of both national government and donor agency expectations.

The reasons postulated for such "poor performance" of irrigation systems are many and varied - reflecting the many professions involved and their particular perspectives of what irrigation development should produce. These "expert analyses" typically offer specific reasons such as "inefficiency" and "bad management" for poor irrigation system performance, but are seldom backed by objective, broad-based and definitive research. Consequently, answers as to why a given irrigation system in question is not meeting expectations are seldom presented to the satisfaction of all concerned.

The Terai region of Nepal is a case in point, where both government and donor agencies have placed a high priority on the development of irrigated agriculture in a bid to achieve secure production levels of food grains and other necessary agricultural commodities. However, these initiatives have failed to match agricultural sector growth with the food requirements of Nepal's growing population.

His Majesty's Government of Nepal (HMGN) has recently brought forward a Basic Needs Program, one of the principal goals of which is to double agricultural production by the year 2000. Consequently, interest has increased in the potential for expanding the role of farmer-managed irrigation systems (FMIS) as a means to solve this problem. The common feature of FMIS is that farmers, rather than an agency, control and manage the water from its source to their fields. In most cases farmers have built the system as well. In many developing countries FMIS provide a food security system that is not included in governments' production estimates. The contribution of these systems to subsistence and national economics is considerable, especially in Nepal where FMIS comprise as much as 80 percent of the total irrigation sector.

1.2 Need for Research

It is clear that gains in food production can be made by developing and assisting FMIS, but almost no research has been conducted to determine the extent of development assistance that may be required. Engineers and planners assume that the lack of control structures in FMIS indicates that water is being used inefficiently. The performance of these systems must be measured to test this assumption, since it is directly related to decisions to intervene in these systems in order to expand the area irrigated or to intensify the cropping pattern.

Both Biswas (1989) and Canadian International Water and Energy Consultants (CIWEC, 1989) emphatically state the need for information and hard data on FMIS performance and its extent in Nepal. In developing the Master Plan for Irrigation Development in Nepal, CIWEC (1989) states that: "system-by-system estimates of actually irrigated areas in summer and winter, and of irrigation capabilities and development intensities cannot be accurately made for FMIS with the level of information available at present... only highly generalized and tentative indications can be made... these indications are needed to allow some master planning assessment to be made with respect to potential improvements to farmer-managed irrigation schemes." While Biswas (1989) adds that: "the desirability of or the necessity for the involvement of the public sector agencies and donor organizations... is still not clear... hard facts and figures are urgently necessary for a reasonable number of projects covering some representative systems. This information will allow clear insight into their cost-effectiveness and long-term sustainability... additional steps that can be taken by all parties concerned to improve their performance should be outlined."

Efforts are already underway to improve the performance of irrigation systems. Thus it is imperative that effective policies be immediately developed to ensure that outside involvement to further develop the potential of FMIS is truly beneficial to farmers and does not jeopardize the long-term contribution of FMIS to Nepal's agricultural base.

Chambers (1988) cautions that:

> "... many past attempts to improve (irrigation system) performance have failed because of defective analysis. In the past, studies and recommendations for canal irrigation have been dominated by the normal professionalism of the irrigation professions, especially irrigation engineering and agronomy... but neither is at all equipped, nor have irrigation engineers or agronomists often been inclined to look far beyond their disciplinary boundaries. Yet commonsense suggests that any realistic agenda for reform should be based upon an understanding of irrigation systems as wholes, including their several domains, dimensions and linkages."

1.3 Objectives

The objective of this program of intensive field research was to use quantitative measurements and detailed observation over a significant period of time in order to evaluate the performance of a large farmer-managed irrigation system in the Terai region of Nepal. Evaluating the performance of an irrigation system in this context can determine the degree to which the inputs to the existing system result in acceptable outputs.

Specific objectives of this study include the following:

i) To observe irrigation activities and to collect water availability and water use measurements over an extended period of time when the water supply is typically scarce, namely the dry season.

ii) To determine through the application and analysis of a number of performance measures to the data, the relative level of performance of the irrigation system as measured against the goals of (a) the system's managers, (b) performance norms of other systems in the region, and (c) national development objectives.

iii) To determine the strengths and weaknesses of the irrigation system in order to assess the potential for expanding the role of the FMIS within Nepal's irrigation sector.

iv) To produce recommendations for appropriate improvements and assistance to this FMIS.

1.4 Measures of Performance for Evaluation

Chambers (1988), has cautioned that adopting a narrow approach to performance evaluation is counter-productive since it ignores or misses a great deal of information that is critical to understanding the irrigation system in its entirety. On the other hand, a complex assortment of engineering, sociocultural, economic and agricultural factors may be difficult to analyze. What has been attempted through the research and analysis presented here is to develop and utilize a balanced approach to performance evaluation. A limited number of quantifiable measures used in this study provide for a detailed examination of the physical irrigation system together with the important related systems - management and agriculture. In this way a wide range of perspectives can be represented.

Specific measures of irrigation system performance employed in this study include:

i) <u>Water use efficiency</u> - at the field, branch canal, sub-system and main system levels; to determine the proportion of the water supply which is effectively utilized for crop production, together with the location and proportion of water losses in the system.

ii) <u>Water allocation and equity</u> - where actual water distribution practices are compared with the established water rights to determine the level of equity and fairness of the water distribution.

iii) <u>Water supply adequacy and timeliness</u> - to determine whether the available water is sufficient to meet the demands of the crop water requirements (adequacy); and by establishing the relationship between the timing of the water delivery schedule and the crop water requirements

(CWR) at critical growth stages, to determine possible crop stress effects (timeliness).

iv) Cropping intensity - the percentage of the total irrigable area that is under production for each crop, to determine the degree to which land use is maximised.

v) Crop production - the yields of each crop grown, to compare to target values.

All these indicators of performance must relate the actual (measured) performance to a specified target or expected level of performance. Performance targets are outlined in Section 5 with the analysis of the performance measures.

1.5 Literature Review

The broad scope of this thesis has rendered a separate review of pertinent literature impractical. Many references have been reviewed and are cited throughout this work.

Chapter 2 incorporates references providing background information about Nepal, and definitions of the subject.

Chapter 4 incorporates references which support the methodology used and describe the technical aspects of the research.

Chapter 5 provides data and information from various sources for comparison and interpretation.

CHAPTER 2

BACKGROUND

2.1 Geography

The Kingdom of Nepal is a small land-locked country in South Asia, bounded by Tibet (the Xizang Autonomous region of China) to the north, and by India to the west, south and east (refer to Figure 2.1). At its longest point, Nepal stretches 885 km from east to west, and its broadest distance from north to south is 201 km. The total area is 14,072,000 ha - roughly twice the size of New Brunswick. 2,968,000 ha of Nepal (or 21 per cent) is estimated to be arable. The capital city, Kathmandu is situated approximately in the centre of the country.

Nepal is composed of three geographical zones running from east to west (refer to Figure 2.2). The Terai is the southern-most zone with 27 per cent of Nepal's physical area, of which

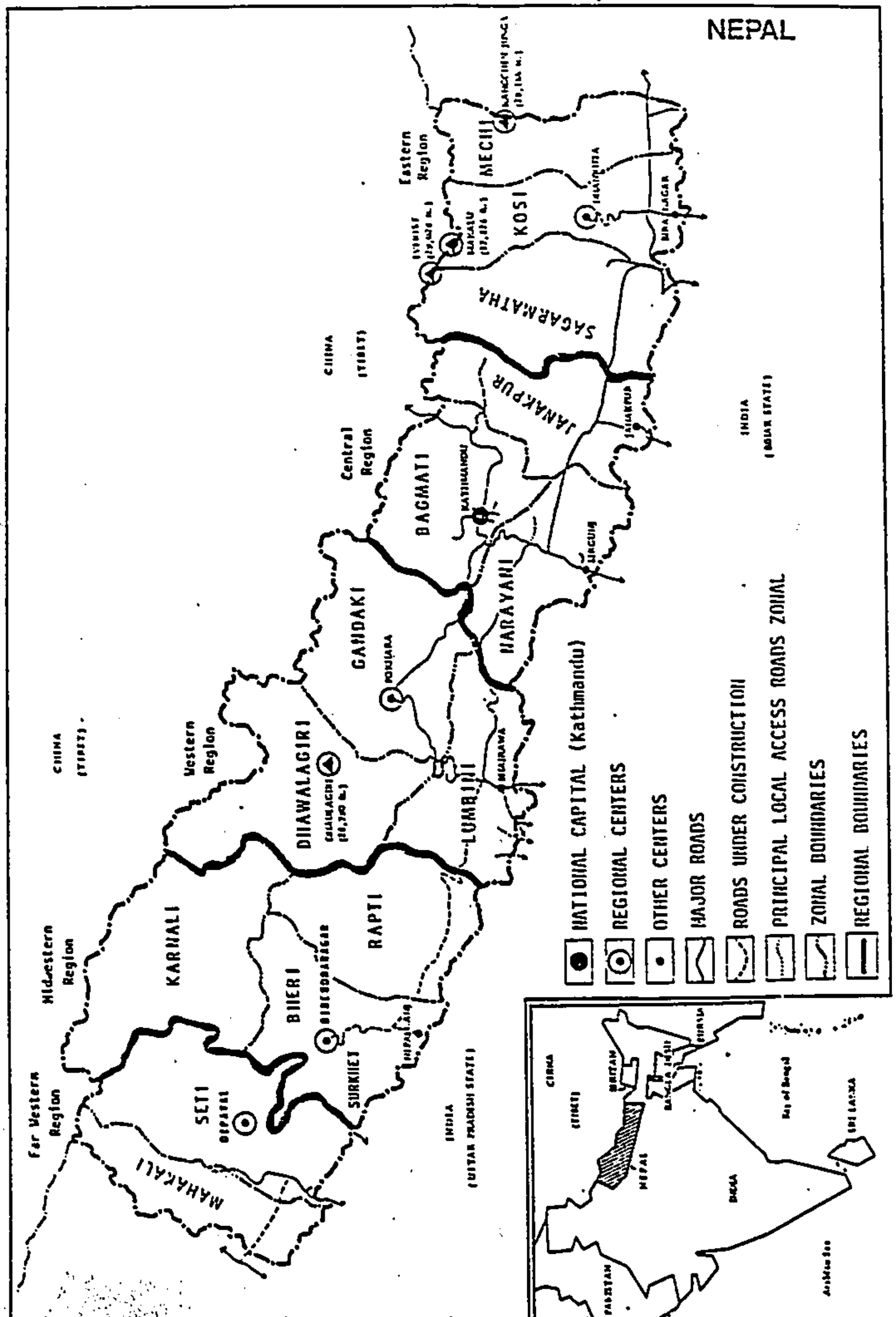

Figure 2.1 Nepal - Major regions and centres (CIDA, 1989)

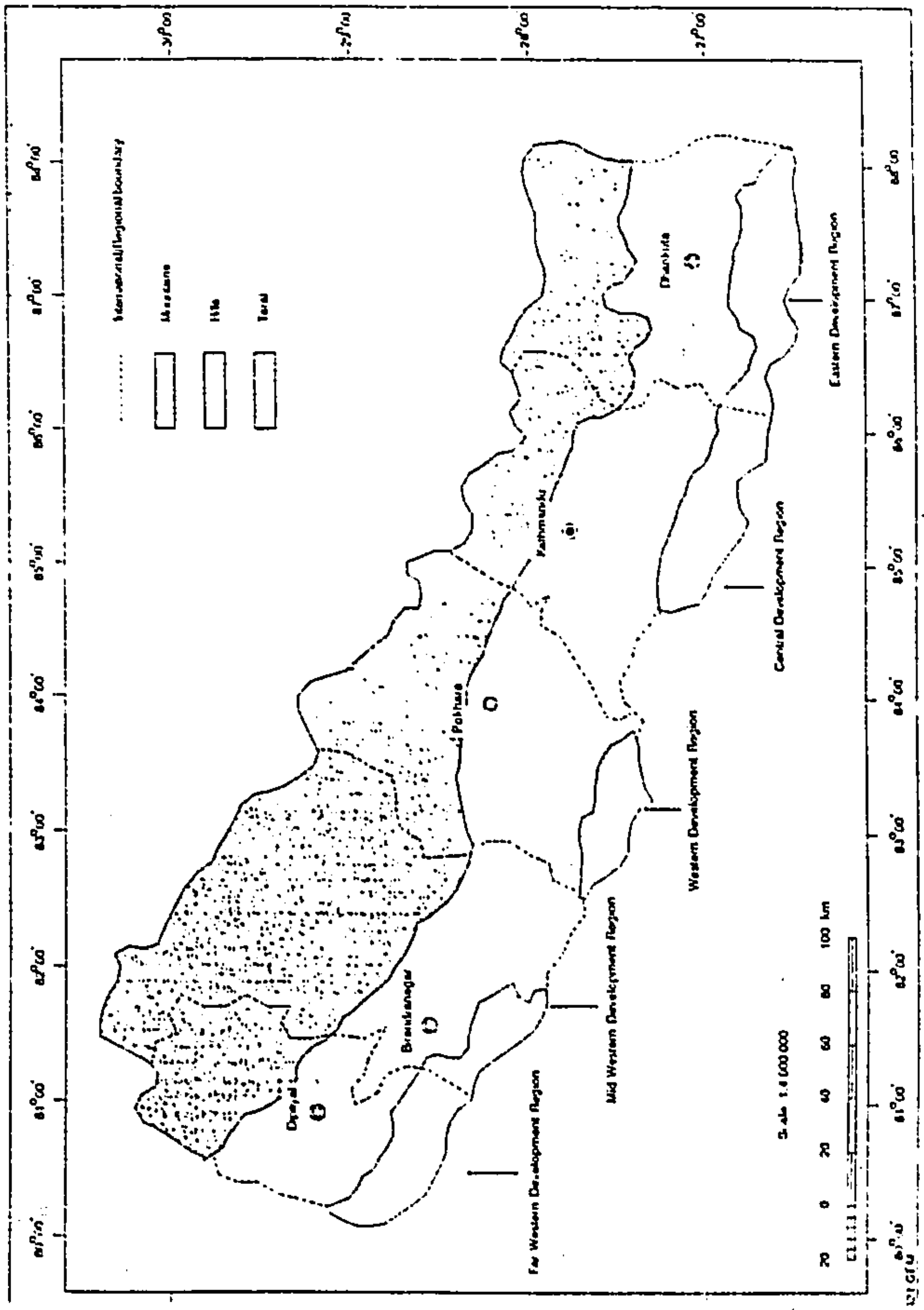

Figure 2.2 Nepal - Main geographical zones
(Sir M. MacDonald, 1989.)

51 per cent is estimated to be cultivated (refer to Table 2.1). The hill area comprises 30 per cent and the mountains 40 per cent of the total area. Nepal is most well known for its Himalayan mountains, particularly Sagarmantha (Mount Everest), the world's tallest.

As the northern most part of the Gangetic Plain, the Terai forms a narrow belt of alluvial plains along Nepal's border with India, varying in elevation from 45 m to 182 m above sea level. Until its recent control, malaria restricted human activity in the Terai and most of the area was forested jungle. Much of the forest has now been cleared to bring more land under cultivation with its rich alluvial soils.

To the north, the Siwalik foothills rise sharply from the Terai plains, which in turn give way to the Mahabharata range of the Himalayas. The hill region is characterized by ridges of steeply sloping mountains. Deforestation and the consequent erosion and slope instability are widespread, while the development of a good transportation (road) network has been limited.

Nepal's climate varies widely depending on altitude and season. In general, all but the most mountainous regions of Nepal have three seasons: the hot and humid monsoon, from June to October, the cool winter from November to March, and the

Table 2.1 Land area, cultivation and irrigation by geographic zone (Sir M MacDonald, 1989)

Ecological zone	Physical Area		Cultivated Area		Irrigated Area[1]	
	`000 ha	%	`000 ha	%	`000 ha	%
Mountains	6280	43	252	8	-	-
Hills	4445	30	1222	41	195[2]	18
Terai	3995	27	1494	51	889[3]	82
Totals	14720	100	2968	100	1084[4]	100

Notes: [1] "Irrigated area" is defined as land having irrigation infrastructure. This does not mean that this land is actually irrigated.

[2] 150 000 ha farmers' built schemes assumed.

[3] 500 000 ha farmers' built schemes assumed.

[4] Assumes 434 000 ha developed by government agencies, including 70 000 ha by ADBN.

Sources: Land resources Mapping Project (LRMP), Land Utilization Report, 1986.

Irrigation Development in Nepal, S.N. Poudel, 1986.

Draft Working Policy Paper on Irrigation Development for the Fulfilment of Basic Needs, DOI, 1988.

hot, dry period of April and May. The Terai is much hotter year-round than the hills which tend to be more temperate.

The average annual precipitation of Nepal is about 1500 mm, with the pattern of precipitation decreasing from east to west. Eighty per cent of precipitation falls in the monsoon season (mid-June to mid-October), and flooding in the Terai often results.

The average annual run off from the country is about 6500 m^3/s, and given the seasonability of precipitation, about 80% of the discharge from the ten major rivers occurs during the six months from June through November. Average total monthly run off is greatest in August at approximately 20,000 m^3/s and lowest in March at 1250 m^3/s.

Four major adjoining river basins running consecutively from east to west cover over 70% of Nepal, including virtually all of the hill and mountain area; these are the Sapta Kosi, Narayani (Sapta Gandaki), Karnali and Mahakali river systems. These rivers originate in the Tibetan plateau and are fed by snow and glacier melt, in addition to the heavy monsoon rains in the hills (WECS, 1981).

2.2 Population

Nepal's population was estimated to be 17.6 million in 1986 (EIU, 1986) and will approach 20 million by 1990. The demographic situation in Nepal is among the worst in the world and is deteriorating rapidly. At the current rate of 2.7 per cent annual population growth, the population is expected to reach 24,480,000 by the year 2000, and 37,610,000 by 2020.

Nepal's population density averaged more than 120 per square kilometre in 1986, but the distribution is quite uneven, with the cultivated areas having an average density of 356 persons per square kilometre. Most of the population lives in the hill zone, but as their numbers have increased they have been forced to cultivate increasingly marginal land. As land has become very scarce in the hills, considerable migration has occurred during the last thirty years from the hills to the low-lying Terai. Now 44 per cent of Nepal's population lives in the Terai, where the population density has become the highest in the country.

2.3 Economy

The challenge of economic development is the most important domestic issue facing Nepal. Ranked by the World Bank as one of the world's least developed nations, Nepal's economy is characterized by a subsistence and non-monetized agricultural sector, a small industrial sector, a negative trade balance, and a high dependence on foreign aid, remittances and tourism. Nepal continues to struggle against its geographical constraints: insufficient arable land, poor internal communications and transport, and a lack of efficient external trade routes. The Gross National Product (GNP) in 1985 was US$2.6 million, or US$160 per capita, ranking Nepal among the world's ten poorest nations. Between 1973 and 1985, GNP growth averaged only 0.5 per cent per year. The annual growth of the overall Gross Domestic Product (GDP) has been more encouraging, reaching 4.2 per cent in 1985/86 (CIDA, 1989).

Agriculture is the dominant sector of the Nepalese economy, in which more than 90 per cent of the population are engaged in producing about 60 per cent of the GDP. Production however, has not been able to keep pace with the rapid growth in population and consequently per capita food availability has declined steadily. In 1980 Nepal became a net food importer for the first time in its history. (ADB, 1982 and EIU, 1986).

During the last fifteen years, the contribution of the agricultural sector to total GDP has fallen steadily to a low of 53 per cent in 1988, that was of a total GDP of 68,145 million Rupees (CDN$2,839 million) in 1987/88 (24 Rs. = 1 CDN$). Productivity in the agricultural sector is poor. In 1987/88 the 8.5 million people who worked in agriculture generated 4,250 Rupees (CDN$177) per person, while the 0.9 million who worked in other sectors of the economy generated 35,800 Rupees (CDN$492) per person (CIWEC, 1989).

Although direct productivity in agriculture is low, a thriving agriculture sector is essential for the welfare of the population and the growth of the national economy. Agriculture provides nearly all the basic food requirements for the population, about 80 per cent of raw materials for the manufacturing and handicrafts industries, and is also the source of most merchandise exports. Agriculture's importance is accentuated by the recent inability of domestic production to keep pace with the nation's food requirements. Table 2.2 illustrates the current food deficit situation.

Table 2.2 Estimates of national and zonal foodgrain balances: mid 1980'S (CIWEC, 1989)

Zone	Population (1985) ('000,000)	Cereal Grain Production (1000 T)	Cereal Grain Require-ments[1] (1000 T)	Balance (1000 T)	Percent self-sufficiency (%)
Mount-ains	1.36	195	341	-146	57
Hills	7.67	1535	2095	-560	73
Terai	7.63	2662	2424	+238	110
Total	16.66	4392	4860	-416	90

[1] No allowance has been made for export requirements in these calculations.

In its Nepal Agriculture Sector Strategy, the Asian Development Bank (ADB) stated that:

> "A rapid and sustained increase in agricultural production is necessary to meet a growing demand for food in the country, to raise income and to provide employment opportunities for the overwhelmingly large portion of the population dependent on agriculture. Development of agriculture is also needed to provide onward linkages to industries and to increase exports to earn foreign exchange required for financing the importation of imports needed for higher growth. In fact the future pace and course of economic development on the country will depend largely upon the growth of agriculture."
> (ADB, 1982).

2.4 Irrigation in Nepal

2.4.1 Background

2.4.1.1 History

The history of irrigation development in the Terai is not well documented, although elaborate irrigation systems in some hill kingdoms are described as early as the 1600's (Pradhan, 1985). Although access to, and consequently development of the Terai region was limited over the centuries, a number of older Tharu (an indigenous Terai ethnic group) schemes have been in existence for many years (WECS, 1981). At the end of the 1960's, with implementation assistance from India and financing from the major lending institutions, Nepal embarked upon an ambitious irrigation sector development program with particular emphasis on the Terai.

2.4.1.2 Water Resources and Irrigation Development Potential

Nepal is endowed with abundant water resources as was outlined in Section 2.1. If the surface and groundwater supplies can be adequately controlled and utilized, it is estimated that most of the 1.5 million hectares of cultivated land in the Terai could be irrigable. With assured water supply due to irrigation and provision of drainage where needed, there exist possibilities of planting two or often three crops, thereby increasing cropping intensities to between 200 and 300 per cent.

However, the costs to develop surface water sources are prohibitive. Many of the rivers are seasonal, and the water supplies are neither timely nor predictable, particularly for land preparation for the main monsoon rice crop. Heavy sediment loads, frequent flooding and unstable river courses make effective water abstraction and sediment control very difficult. Other constraints to surface water development include a shortage of suitable storage sites, difficulty of access to most hill areas, and riparian water rights issues.

The potential for groundwater development in the Terai is considerable. Existing installations in operation include approximately 16,000 shallow tubewells and 200 deep tubewells supplying irrigation water to an estimated 77,000 ha. A recent study postulated that groundwater schemes could be expanded to cover 350,000 ha, supplementary existing rain-fed cultivation for the most part, but also augmenting existing surface water supplies in some areas. (Sir M MacDonald, 1989)

The potential for expanding the irrigated area in the hill zone is very limited, as 195,000 ha of the 250,000 ha that is estimated to be suitable for irrigation (almost 80%) have already been developed (Kenting, 1986). FMIS account for 77 percent of the existing irrigated area. Increases in agricultural production in the hills may be achieved mainly by increasing crop yields and cropping intensities. Therefore irrigation development in this region should concentrate on improving the reliability of water supplies.

Most recent surveys indicate that 1,727,000 ha of land in the Terai is suitable for irrigation, of which 889,000 ha receives some irrigation at present (Sir M. MacDonald, 1989). However, if wildlife reserves and forested areas (about 600,000 ha) are excluded, the irrigable area is reduced to 1,130,000 ha, thus only 21 percent of the potentially irrigable area in the Terai remains to be developed. FMIS constitute an estimated 500,000 ha or 56 percent of the presently irrigated area and may benefit from technical improvements that would facilitate intensified cropping within these systems. The potential for development of FMIS through intensification, technical improvement and expansion is high. In addition, many of the existing government schemes are not functioning near optimum efficiency levels, and output could be significantly improved.

Terai schemes are mostly medium to large size surface water schemes with fairly flat command areas. There are also a number of small to medium groundwater schemes. Most (56%) of the irrigated area in the Terai is comprised of 1700 FMIS with command areas between 5 and 15,000 ha. The remaining Terai schemes are managed by the DoI or other Government agencies and are generally large scale, ranging in size from 160 to 68,000 ha. (Sir M. MacDonald, 1989)

2.4.2 Present Status - Area Irrigated

The total command area irrigated is an important indicator of the progress of irrigation development, and particularly for evaluating the level of success of government programs. However, the lack of concise data requires that reported figures be examined critically. Reported command areas often exceed the real command areas. The same command areas may often be reported more than once (duplication or double-counting), and existing FMIS may be reported as new DoI schemes (overlap), (CIWEC, 1989). Much of the recently published data presented in the tables below is largely based on estimates and therefore sources may sometimes be contradictory of each other.

Table 2.1 shows that most of the irrigated area in Nepal is in the Terai. Table 2.3 summarizes the results of a comprehensive

Table 2.3 Summary of water resources inventory study of 20 Terai districts (WECS, 1989)

Category			Total
Zone			8
District			20
District Area (ha)			3,416,231
Cultivatable Land (ha)			2,063,560
Cultivated Land (ha)			1,502,258
Potential Irrigable Land (ha)			1,821,156
Surface Irrigation Gross Irrigated Area (ha)	Farmer's Sector	Seasonal	320,550
		Year Round	205,002
		Total	525,552
	Public Sector		234,674
Groundwater Irrigation Gross Irrigated Area (ha)		Farmer's System	16,782
		Public Sector	19,909
Total Irrigated Area (ha)			796,917
Surface Irrigation	Nos. of Locally Developed Canal Systems		1,925
	Government Projects		30
Groundwater Irrigation Number of Tubewells		Farmer's Sector	2,754
		Public Sector	1,286

field survey conducted by WECS in 1988 from which an inventory of existing irrigation systems in the Terai has been compiled.

2.5 Irrigation System Defined

By definition, a system is a group of parts (or subsystems) working together. Irrigation is the supply of water to agricultural crops by artificial means, designed to permit farming in arid regions and to offset drought in semiarid or semi-humid regions (Hillel, 1987). The fundamental objective of any irrigation system is to convey given quantities of water to particular places at certain times - in short, to distribute water where, and when, and in the best manner for crop production. This defines the objective of the irrigation system in the narrow, physical sense.

The physical irrigation system may be divided into four subsystems or processes: water delivery, water application, water use and water removal. The purpose of each subsystem is as follows:

- Water Delivery: to convey water from the water supply source by way of the main canal and distributary canals (or pipelines) to a canal outlet, and from there through farm and field channels.
- Water Application: to distribute water over the field to fulfil the water requirements of the crop.
- Water Use: to store and supply water to plants for crop production.

- Water Removal: to remove excess water to maintain conditions for optimum crop production. (Podmore, 1983).

The process of irrigation consists of introducing water into the part of the soil profile that serves as the root zone, for the subsequent use of the crop. A well-managed irrigation system is one that optimises the spatial and temporal distribution of water so as to promote crop growth and yield, and to enhance the economic efficiency of crop production. But irrigation is not simply an exercise in mechanics or economics. It is a human activity and a social undertaking (Hillel, 1987).

In the broader sense then, a definition of the irrigation system would include the following: water, the physical irrigation infrastructure to control and distribute the water, a management (or social-organizational) structure to control the water and physical infrastructure, an agricultural production system for which the water is used, and an economic system which provides the incentive for agricultural production.

2.6 Related Systems Defined

"Failure to grasp the vital principle of interaction of systems components is the greatest technical handicap to agricultural development in the newly developing countries." (Podmore, 1983.)

Since an irrigation system is itself comprised of several diverse but related systems, disciplinary lines must be crossed so as to accurately describe and understand the farm irrigation system in its entirety. These systems are interdependent. The management structure, like the physical infrastructure, enables water distribution to occur. The agricultural system and economic or agricultural economic system renders water distribution worthwhile. But it is the distribution of water that lies at the heart of the performance evaluation. These related systems are briefly defined below.

The cropping or agriculture system may be defined as all of the elements required for the production of a particular crop or a set of crops, and the inter-relationships between the crop or set of crops and the environment. The function of the agriculture system is to produce food, fibre, and other organic products at optimum levels with the desired quality and to insure long-term productivity. Implied in both the definition and function of an agriculture system is the interdependency among the crop system, man (the manager), and the natural environment (the input). How the agriculture system functions is in turn dependent on the pattern of cropping, the plant environment, climate, soil type, pests, and the management practices of the farmer.

The management system may also be termed the social-organizational system as the management of the irrigation system is through the collective efforts of an organized group of people. The management system operates and controls the irrigation system in the production of crops. Since irrigation is such a strongly social process, some form of organization must exist in an irrigation system to provide even a minimal operational efficiency. If there are two or more potential users of the water, collective action by users must occur to manage the system. Therefore, how well the users are organized will greatly effect the management of the water resource; defects in water delivery, application, use and removal will often be the result of problems in the social organization of the irrigation system.

Human and natural resources together with certain organizational procedures are required and must be collectively mobilized by water users to effectively manage an irrigation system.

People must, in the first place, organize to create and maintain irrigation works. Water is only delivered effectively to the farmer's field, at the correct time and in an adequate amount, when people have organized to supply the water and maintain the delivery system. Thus management can be seen as the decisive factor that ultimately manipulates all the physical components of an irrigation system in order to achieve the desired result.

The economic system is concerned with the productivity and efficient allocation of agricultural resources. Consequently it may also be termed the agricultural economic system. Land, labour, capital and management are the principal productive resources. The allocation of these resources is based on identifying and verifying economic efficiency, that is, the optimal allocation of resources so as to maximize profit or income (Podmore, 1983).

2.7 Performance Evaluation Defined

2.7.1 Definitions

"Performance evaluation" implies the study of a subject to assess the quality of its operation with respect to certain established criteria and standards. In this case the subject is an irrigation system (and its related sub-systems), which is in turn broken down into its functions and processes for analysis. Field study and observation generates data and information which is analyzed to evaluate the irrigation systems' performance against established targets and standards for its operation. Abernethy (1989) states that "performance is a generic term that is commonly used to denote the aggregate results delivered by an irrigation system. It represents the outcome of human actions, including management actions, upon some given set of physical irrigation facilities." Performance in its own right may be defined in this context as "the degree of satisfaction that people (and/or agencies) involved in at least one of the irrigation processes get out of their irrigation related activities" (Berthery, 1986).

Abernethy (1989) proposes the simple definition which follows:

"The performance of an operating system is the degree to which the system achieves its declared objectives."

A definition of this sort has a role in irrigation management; but it is a limited role, since the definition contains some objectionable features. It makes performance a relative, not an absolute quantity; and it is relative to targets that are subjective, and that vary with time. We may therefore use the expression "relative performance" in connection with the above definition, and reserve the term "performance" alone for absolute measures. In this latter sense, the following definition may be adopted:

"The performance of a system is represented by its measured levels of achievement in terms of one or several parameters which are established as indicators of the system's goals." (Abernethy, 1989)

2.7.2 Clarifications

In defining performance evaluation, Sally (1986) makes it clear that evaluating the performance of irrigation systems should be distinguished from evaluating the impact of irrigation. Questions of scale and time-frame have to be considered. Evaluating performance could be thought of as a relatively short-term undertaking (seasonal or annual) whereas evaluating impact (especially social or economic) would require a much longer time horizon.

Further to the definition, Small (1986) states that performance evaluation can be of two fairly distinct types: descriptive and analytical. <u>Descriptive</u> evaluations identify the <u>results</u> of irrigation actually achieved as compared with certain targets, standards or objectives. <u>Analytical</u> evaluations identify the <u>reasons</u> for the results achieved. Because one must know the results before the reasons for the results can be identified, descriptive evaluation is a necessary step in providing the information needed for analytical evaluation.

The primary conceptual issues (or objectives) with respect to descriptive performance evaluation are: (i) the determination of the appropriate boundaries for evaluating irrigation performance, (ii) determination of the measures of performance to be used, and (iii) the determination of the appropriate target levels or standards for each of these measures. Of course, once these issues have been resolved there are a variety of methodological issues which need to be addressed as they are later in this thesis. Descriptive performance measures can be made more meaningful only if relevant contextual information can be incorporated into them or displayed along with them. The challenge is to find a simple and concise way of doing that given the complexity normally encountered in irrigation systems and the need to consider not one but many performance measures.

Analytical evaluation is conducted to identify the reasons for unsatisfactory performance and must be based largely on the skill and insights of the individual evaluator. Consequently it is not useful to try and specify standard approaches. Analytical evaluation requires expertise in various disciplines and may require a shorter or longer term commitment than for descriptive evaluation.

Irrigation performance is the end result of the process of planning and design, construction, operation and maintenance, irrigated farming, and, in some cases rehabilitation. Any shortcoming in irrigation performance may be traced to shortcomings in one or more of these processes. Therefore, a useful way to consider an analytic approach to performance evaluation is to try to identify the reasons for unsatisfactory performance in terms of these processes.

In short, performance evaluation involves the documentation of performance levels achieved and analysis of the factors responsible for the observed levels of performance.

2.7.3 Purpose of Performance Evaluation

From the perspective of planners and designers, the American Society of Agricultural Engineers (ASAE) states that "the purpose of evaluating irrigation systems is fourfold:

i) to determine the efficiency of the system as it is being used;

ii) to determine how effectively the system can be operated and whether it can be improved;

iii) to obtain information that will assist engineers in designing other systems; and

iv) to obtain information to enable comparing various methods, systems and operating procedures as a basis for economic decisions." (ASAE, 1983).

Researchers may evaluate the performance of a small subsystem in order to obtain a deeper understanding of the processes at work, or they may study the irrigation system as a whole. From his experience in researching the performance of farmer-managed irrigation systems (FMIS), Yoder (1986) states: "...we undertake (performance evaluation) studies to explore the farmers' experience with irrigation and to evaluate the performance of the methods and technologies that they have evolved to meet the demands of their environment"; and that the "identification of the limitations of FMIS can provide a useful starting point for outside development assistance to FMIS".

Managers may evaluate performance of irrigation systems at short intervals of time in order to obtain feedback, which is then used to improve the operational dimensions and thus respond to changing conditions within the systems. They may also evaluate performance at longer intervals of seasons and years in order to improve the planning and design processes of systems.

2.7.4 Perspectives

The definition of performance evaluation requires that the search for and selection of measurable indicators of performance must start with consideration of the objectives or goals of the irrigation system in question. Irrigation system goals might be generally classified under five main categories: productivity, equity, profitability, sustainability and quality of life. The particular set of performance measures employed in this study have already been outlined in Section 1.4. While some of these performance indicators are easy to define and quantify, others are not. Therefore evaluators must resist the tendency to equate measurability with performance.

Consideration must also be given to the particular perspective from which the performance of the irrigation system might be viewed. There are many participants in an irrigation enterprise and it cannot be assumed that they all share the same view as to what constitutes good performance. Small (1986) has categorized the perspectives of various groups on the basis of their function or role in the irrigation process as follows:

i) Potential recipients of irrigation services (farmers or water users),

ii) Providers of irrigation services (irrigation agencies or farmer management organizations),

iii) Planners of irrigation services (national government policy and planning agencies),

iv) Financiers of irrigation services (donor/lending agencies, national governments, the general public and farmers),

v) Special interest groups: those with commercial interests in project planning, construction and operation (consulting firms, construction companies), those with commercial interests in irrigated farming (farm labourers, agricultural input suppliers, marketing firms), and those with political interest.

Although these different actors involved in irrigation may be concerned with the same basic measures of performance, they are likely to have differing objectives or targets and thus differing perspectives of what good performance should be. For example, finance ministries and lending agencies may stress the production of crops for export (or import substitution) in order to repay the loans for irrigation construction, and will also seek to minimize the recurrent expenditure on operation and maintenance. National planning agencies may be primarily concerned with the extent to which irrigation is serving as a stimulus to general agricultural development. Irrigation agencies are concerned primarily with how water is distributed throughout the irrigated areas, and that its utilization to produce crops is not their concern and therefore not an indicator of their performance. Agricultural departments may research crop water requirements and define "optimal" cropping patterns, but farmers may choose not to adopt them because they are poorly matched to household needs. While water users (farmers) are likely to be primarily concerned with their ability to obtain adequate amounts of water in a timely and convenient manner to support their desired cropping patterns.

Robert Chambers (1988) has noted that beyond general statements regarding the objectives of irrigation; each group, discipline, profession and department has its own concerns, its own values, and its own priorities, especially at the level of criteria for (or measures for) performance. Asked to give their first criterion of good performance of a canal irrigation system, different people are likely to give initial answers reflecting their personal and professional interests. Some responses might be on the lines of Table 2.4.

Yoder (1986) also cautions that "in evaluating irrigation performance, one must carefully consider the primary purpose for which the irrigation systems have been built... for instance... many irrigation systems in Nepal have been built with the primary purpose of irrigating rice (supplemental irrigation) during the monsoon." Consequently, to evaluate the performance of such a system from the national planner's perspective of maximizing overall agricultural production through intensive multiple cropping may result with finding the system to be performing poorly. Whereas, in the farmer's eyes, his system may be meeting his needs in a reliable and sustainable manner.

Ideally, therefore, research should focus on evaluating irrigation performance from the perspectives of irrigation agencies (or farmers organizations as the case may be) and of water users. It is these perspectives which are most directly linked to the functions which the irrigation facilities perform, namely, the distribution and delivery of water for crop production. This allows the evaluation of performance to focus most directly on irrigation relative to its direct purpose of supporting crop production. It should be recognized, however, that the perspectives of an irrigation agency will be affected by the policy environment in which it operates. This policy environment creates external influences and directions to which the irrigation agency responds, and which affect its perceptions of irrigation performance. (IFPRI and IIMI, 1988).

2.7.5 Standards for Indicators

For performance indicators themselves to be effective, they must satisfy certain standards, such as:

- They must be quantifiable, at a sufficient level of accuracy. Therefore they must not be erratic or volatile, nor unduly affected by the measuring technique. Thus where sampling techniques must be used (in crop production estimates for example) the sampling density must be chosen with these factors in mind.
- They must be communicable. Successful irrigation systems require the active cooperation of farmers with engineers and other types of agency officials, who must share similar perceptions of system performance. Indicators must therefore be measured in terms that are easily understood and that help to advance mutual understanding.

Table 2.4 Criteria of good system performance according to type of person (Chambers, 1988).

Type of person	Possible first criterion of good system performance:
Landless labourer	Increased labour demand, days of working and wages.
Farmer	Delivery to his or her farm of an adequate, convenient, predictable and timely water supply for preferred farming practices.
Irrigation engineer	Efficient delivery of water from headworks to outlet.
Agricultural engineer	Efficient delivery and field application of irrigation water, from the outlet to the root zone of the crop.
Agronomist	Creation and maintenance of the optimum moisture regime and plant growth and in particular maximising production of that part of the plant which is the harvestable product.
Agricultural economist	High and stable farm production and incomes.
General economist	A high internal rate of return.
Political economist	Equitable distribution of benefits especially to disadvantaged groups.
Sociologist	Participation of irrigators in management.

- They must be inexpensive - that is the cost of performing the necessary measurements on a routine basis must be affordable (IIMI, 1986).

CHAPTER 3

RESEARCH SITE SELECTION AND CHARACTERISTICS

3.1 Research Site Selection

3.1.1 Reconnaissance Survey

The inventory of farmer-managed irrigation systems (FMIS) in the Terai completed by the Water and Energy Commission Secretariat (WECS) in 1988 was studied by International Irrigation Management Institute (IIMI) staff, who compiled a list of 54 FMIS which were reported to have command areas larger than 1000 ha. Of these 54 medium and large FMIS, 12 were selected for a field reconnaissance study. These twelve systems were visited during three field trips April through June 1988. Staff from the Irrigation Management Centre (IMC), the Institute of Agriculture and Animal Science (IAAS), and the International Irrigation Management Institute (IIMI) participated together on the reconnaissance team. The purpose of the reconnaissance was to select the most appropriate large Terai FMIS for in-depth research.

The reconnaissance study involved a short (usually one day) visit to each system in order to prepare a profile report which included details of the physical systems, the cropping pattern, management and organizational systems, and any other unique features. A summary of the features of the FMIS visited in the course of the reconnaissance phase is under separate cover. Following this reconnaissance phase, the number of candidate systems was reduced to three, and the final research site selection was made during a fourth field trip in June 1988. The author participated with IIMI in the reconnaissance program and assisted in the establishment of IIMI's research program in the Chhattis mauja[1] irrigation system.

3.1.2 Criteria

The following are some of the criteria which were employed for the final selection of the particular FMIS for the research program:

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[1] village or branch canal area

- the system command area must be greater than 1000 ha, and preferably even larger in order to be recognized as a large Terai irrigation system,
- the system must be accessible to the research team throughout the year,
- the water supply should be perennial, and should preferably be inadequate during some period so that farmers response to water shortages might be observed,
- the system must have been established and developed by farmers without external assistance, and must currently remain under their control,
- the system should be intensively cultivated, with crops grown throughout the year,
- the system's boundaries must be readily definable;
- the system should preferably have opportunity for the expansion of the irrigated area,
- the system should as much as possible be a typical example of FMIS in the Terai,
- the farmers within the system must be willing to accept and cooperate with the research,
- the appearance of an effective management system is essential, together with farmers' capacity to readily explain the system's features,
- the physical infrastructure of the canal system for water distribution must lend itself well to the installation of

flow measurement structures and thereby facilitate accurate water delivery measurements.

3.1.3 Selection of FMIS for Research

In July 1988, the Chhattis Mauja FMIS was selected by IIMI for study, and a field research base was established. The Chhattis Mauja irrigation system is located in the Terai of Rupandehi District, Lumbini Zone in the Western Development Region of Nepal (refer to Figure 2.1). This FMIS, as well as the adjoining Sorha Mauja FMIS, both fulfilled the criteria for selection.

The author assisted IIMI staff in the selection of study areas within the Chhattis Mauja system and the design of flow measurement structures for installation in selected canals.

In September 1988, the author selected the Sorha Mauja FMIS for his own research study. This FMIS met the criteria for selection and possessed a number of interesting and unique features for study. Its location (adjoining the Chhattis Mauja irrigation system) also offered the opportunity to compare the research results with those from IIMI's Chhattis Mauja research program. It was felt that such an exchange of experience and data would strengthen the results from both studies.

3.2 Characteristics of the Sorha Mauja Irrigation System

3.2.1 General

3.2.1.1 Location

The Sorha Mauja irrigation system (SMIS) is situated south of the town of Butwal and is bounded to the west by the Tinau river, to the east by the Chhattis Mauja irrigation system (CMIS), and to the south by the Bhairawa-Lumbini Groundwater Project (BLGWP). Refer to the command area map in Figure 3.1 (back pocket). The SMIS covers Butwal Ward No. 9, and old Anandavan Madhuban Wards Nos. 3, 1, 7, 8, and 9 (from north to south). Its geographic location is at approximately 27° 38′ North latitude and 83° 27′ East longitude. The photo in Figure 3.1 shows much of the command area.

3.2.1.2 Command Area

The overall command area (CA) of the SMIS is estimated to be 1500 ha. On its own, the SMIS would be classified as a medium size irrigation system (refer to Section 2.2.2). However, since the SMIS and CMIS share a jointly managed water source and delivery canal, their combined CA of approximately 5000 ha would classify them together as a large Terai irrigation system. Thus, the SMIS has been termed a "large" FMIS for the purposes of this study and for comparison with other systems (Sir M. MacDonald, 1989). According to the technical level assessment system employed by the DoI, the SMIS would be classified as being of intermediate technical complexity (Sir M. MacDonald, 1989).

The topography of the CA is flat, gently sloping from north to south. The altitude is approximately 130 to 150 m above sea level.

The soils are well drained in the head and middle parts of the CA, where the water table remains a considerable distance below the ground surface. In the middle area, groundwater rises to within two to three metres of the surface during the monsoon season, while in the tail area the water table rises to the surface in low-lying areas and waterlogging becomes a problem.

3.2.1.3 Source of Water

The Tinau river is the source of water supply for five FMIS south of Butwal including the SMIS and the CMIS. The Tinau is classified as a small perennial river (WECS, 1981). The Tinau drains a hill catchment area of 554 square kilometres north of

Butwal. The flow regime of the Tinau varies widely during the year with very high monsoon flood flows and very low dry season flows being the norm. The long-term average flow (from the available data, WECS, 1989) is 23.3 m^3/s.

The SMIS jointly operates and maintains two diversions and intakes on the east bank of the Tinau river with the CMIS. The upper intake is located at "Khanya dhunga" (virgin stone) in the Butwal bazaar area, and the second intake "Ita bhod" (large brick opening) is located about two kilometres downstream from Butwal (refer to Figure 3.1, back pocket). Water is diverted and channelized by temporary spur weirs (constructed with boulders, gabions, stone and brushwood) into both intakes. Water from Kharya dhunga is conveyed in a main canal to Ita bhod, where it joins with the water diverted there, and the combined flows are further conveyed downstream to the Sorha-Chhattis division structure at Taraprasad bhod.

3.2.2 History

The SMIS was founded approximately 85 years ago by indigenous Tharu people, and has experienced an interesting process of development which is detailed under separate cover.

3.2.3 Sub-areas Selected for Intensive Study

Of the 33 maujas in the SMIS, three were selected for intensive study. These three maujas, one each from the head, middle and tail areas of the system, collectively represent 22 per cent of the total irrigated area. These areas are described below.

3.2.3.1 West Siddhanagar

The West Siddhanagar (WS) mauja lies in the upper area of the SMIS, between the Tinau River and the SM main canal (refer to Figure 3.1 in the back pocket). An inlet for WS is located on the west bank of the main canal at Dingernagar, about half a kilometre south of Taraprasad bhod. The WS branch canal travels 260 metres until it reaches the WS command area. The gross command area of WS is 12.3 ha, with an irrigated area of 10.9 ha (16.35 bigha). WS receives a water allocation of 1.5 kulara[2]. There are 32 farmers in WS with an average landholding size of 0.32 ha (0.48 bigha). Most (81%) are land owners.

[2] a share system of apportioning both water supply and labour requirements

The WS branch canal flows south along the eastern boundary of the irrigated area. Each farmer has his own farm ditch with an inlet on the branch canal. All the farm ditches run laterally across the fields from east to west. Thus WS has one of the most systematic and sophisticated water distribution systems in the SMIS. Any drainage water from WS is recovered and flows into the Dingernagar branch canal.

3.2.3.2 Anandavan Madhuban

The Anandavan - Madhuban (AM) mauja lies in the middle area of the SMIS and is the largest mauja (refer to Figure 3.1). AM receives 18 kulara of water allocation and irrigates an area of approximately 300 ha (450 bigha). AM is served by three main branch canals of the SM main canal. The area served by the largest of these AM main branches was selected for study. Water allocation to this branch is 15 kulara for a gross command area of 263 ha (394 bigha). The inlet of the main branch canal is located on the east bank of the SM main canal, 2.8 km downstream from Taraprasad bhod, just north of the Shankar Nagar road bridge.

The Anandavan Madhuban (AM) main branch canal is further divided into five sub-branch canals and several smaller farm ditches which also receive water from the main branch canal. Two such sub-branch areas of the main AM branch system were selected for intensive study - the "Number 10 road" sub-branch (AM#10) and the "7 bigha" branch (AM-7b).

3.2.3.3 Khopiya

Lying in the tail end of the SMIS, Khopiya is part of the Ganeshpur mauja (refer to Figure 3.1). The inlet to the Khopiya branch canal is near the tail end of the SM main canal, almost seven kilometres downstream from the Taraprasad bhod division structure. Khopiya receives a water allocation of 1 kulara which is shared by 9 farmers with 16.2 ha (24.3 bigha) of land.

3.2.4 Irrigation System Management Organization

3.2.4.1 Establishment and Purpose

During the early years of its development, the SMIS was operated by the Tharus who built it. Leadership was provided by prominent men in the community and strict rules of conduct were observed.

The first areas irrigated by the Tharus were in the south, towards Bhairawa, and the system gradually expanded northwards to incorporate what are now the tail-most maujas in the existing SMIS. The system grew more rapidly through the 1950's however, as settlers migrated from the hills to the Terai and expanded the irrigated area further north towards Butwal (covering much of what is now the SMIS). These new farmers had different concepts of how the irrigation system should be managed and operated, and consequently established a committee of elected members to direct and manage the system. External pressures on the SMIS such as the construction of the Tinau dam and diversion (refer to Figure 3.1) must have also played a role as farmers realized the need to form a strong and united group in order to promote and protect their interests. A written constitution was deemed essential and was produced. In 1959 (N. 2016), water users from the SMIS met to elect a committee to manage and direct the operation and maintenance of the SMIS.

The constitution was revised and necessary revisions made in 1979 (N. 2036). The purpose of the "Old Sorha (16) Mauja, New Tettis (33) Mauja Tinau Canal Cooperative Committee Constitution" is explained clearly in the preamble to the revised constitution of 1979:

> Rules and regulations are integral parts of every system, because without them work cannot be undertaken in an organized and disciplined manner. Such rules and regulations included in existing government legislation are not sufficient for our irrigation system and practises. In the operation of our irrigation system we have experienced various problems and difficulties. These

constraints have concerned the people of 33 Mauja (Regions) Tinau Canal co-operative irrigation system.

Although the irrigation system in our village (district) was given the name "Sorha mauja" (Sixteen villages) in the past, this name has now been changed to the "New 33 Mauja" (New 33 Villages). This is because of the increased area of the newly cultivated land, which, when combined with the previously cultivated land incorporates a total command area of 10,000 bigha (or 6,667 ha as 1.5 bigha = 1 ha).

In order to irrigate all these lands, all the people constructed an irrigation canal with voluntary labour, from the Tinau river where it flows through Butwal Khasauli (the Butwal bazaar area). After the completion of this canal, people in this area have been able to grow crops in different seasons, but the question of proper distribution of water remained. They realized that in the absence of proper management, rules and regulations, irrigating the lands of all the people was quite impossible. Therefore, two to three months before the monsoon crop cultivation, all the consumer-farmers from 33 Mauja gathered in the central part of that area and formed a body from among themselves by an election. They tried to elect to that committee selfless and impartial members (volunteers), and they made a rule to dissolve and elect this committee every year at the same time. The committee was formed with the intent to conduct the irrigation system in a proper way, as it was in the past. Moreover, the objective was to resolve any problems and hindrances in the irrigation system. With this objective we all agreed, passed the act, and signed it. Then we delegated these responsibilities to the committee with the hope that they will work in accordance with the act.

If somebody contravenes this Act, does not pay any fine levied against them, and is not ready to bear any punishment and warning given by the committee; the appropriate authority of His Majesty's Government with the help of the Articles under this Act, may take action in the form of a fine, penalty or other punishment according to the fault. Such action is acceptable to all the people of this canal area.

A complete English translation of the Revised Constitution (1979) and its subsequent amendments of 1985 (N. 2042) is under separate cover.

3.2.4.2 Constitution

The first written constitution for the SMIS was written and adopted in 1959. A revised constitution followed this initial effort in 1979, in order to respond to changing conditions within the system.

The Constitution covers the following:

i) composition, election and re-election of the committee,
ii) canal maintenance;
iii) distribution of water;
iv) financial management, and includes an
v) appendix which outlines various operational procedures and regulations.

Amendments to the Constitution were made in 1985 to provide the following:

i) definitions of terms,
ii) composition and role of the general meeting,
iii) formation of the executive committee
iv) allocation of work for annual main canal cleaning (desilting),

v) fines for water theft,

vi) procedures for the election of executive committee members.

3.2.4.3 Organizational Infrastructure

The management of the SMIS is undertaken by a well organized Executive Committee (EC) of elected and appointed officials. An organizational chart illustrating the structure of the Executive Committee is shown in Figure 3.2.

Including the Executive Committee, there are four other levels or tiers of organization:

i) The Tinau Irrigation Committee is comprised of the chairmen from each of the five irrigation systems which abstract water from the Tinau river in the Butwal area. Other local political leaders are also members of this committee. This committee is not a very active one, but its role is to resolve disputes regarding the sharing and appointment of the available Tinau water supply if and when they occur.

ii) The Joint Sorha-Chhattis Committee is comprised of a Chairman, Vice-chairman, three Representatives (two of whom are the Chairmen of the two systems' executive committees), and two Advisors. The

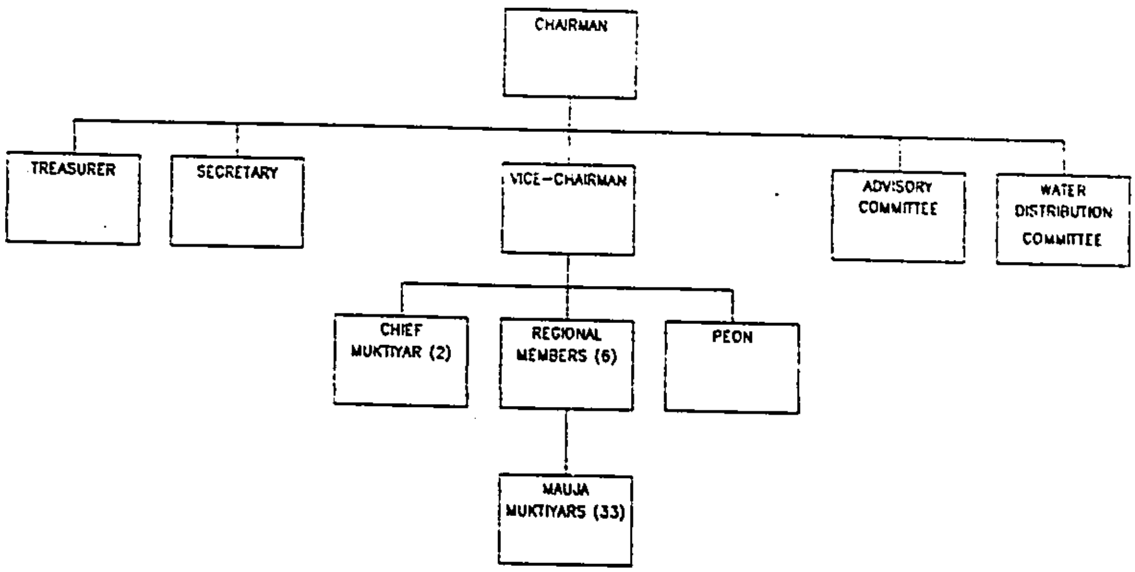


Figure 3.2 Executive committee of the Sorha Mauja Irrigation System, Rupandehi

role of the Joint Committee is to ensure that an adequate water supply is abstracted from the Tinau river, to fairly divide the combined water supply to both the SMIS and the CMIS according to their entitlement; and to mobilize personnel and equipment for constructing river diversion structures, improving and maintaining the jointly used sections of the main canal.

iii) The Sorha Mauja Executive Committee is responsible for operation and maintenance of the main canal water delivery system, distribution and delivery of water to each mauja according to its allocation, regulation and enforcement of all activities within the system related to irrigation, mobilizing resources for construction works, and conflict resolution. The Executive Committee is comprised of a chairman, vice-chairman, secretary, treasurer, six regional members, two chief muktiyars, a peon (messenger), a two person water distribution committee, and an advisor (refer to Figure 3.2).

iv) The thirty-three maujas of the SMIS are divided into six regions, and each region elects a representative to the Executive Committee. Each mauja has its own management group, which varies in size depending on the size of the mauja. Anandavan Madhuban mauja for instance has a chairman (muktiyar), vice chairman, peon, and secretary-treasurer. While West Siddhanagar, a much smaller mauja, has appointed a chairman.

3.2.4.4 Resource Mobilization

Effective operation and maintenance of the SMIS requires the mobilization and use of a number of resources. These resources may be available internally (that is, from within the irrigation system) or externally. Resources might also be categorized as financial, manpower, or materials.

Resources available within the SMIS include:

- labour for construction and maintenance works;
- cash raised from fines or by special appeal to farmers for specific projects;
- farmers expertise in the areas of management, construction and irrigation;
- locally available materials such as stone, sand, gravel, and brushwood (increasingly harder to obtain).

External resources which have been provided to the SMIS include:

- cash grants from government and/or donor agencies;
- grants of construction materials and the use of heavy equipment;
- technical expertise.

Records of maintenance labour and finances for the past two years (refer to Table 3.3) indicate a high level of internal resources mobilization.

The annual desilting of the main canal is the most significant mobilization of resources through the year (refer to Figure 3.5). Long-time committee members estimate that approximately 6,000 person-days of labour are expended every year for this purpose. In 1989 15 days were required to complete the desilting work with 4687 person-days of labour. (The total person-days of labour called for was 5773.5, and a total of 1086.5 absentees were recorded.)

Other details regarding the system of labour mobilization are included in the constitution and may be found under separate cover. Further description and the detailed records of maintenance activities which were recorded during the course of this research are also compiled under separate cover.

Table 3.1 Records of labour for maintenance (Kulahi) and financial summary

YEAR - GREGORIAN Calendar (NEPALI Calendar))	1988-89 (2044)	1989-90 (2045)
Number of Days Kulahi Called	83	102
Total Number of Kulahi	153	191
Number of Kulara in the System	94	93
Total Required Person-days of Labour	14,382	17,763
Total Absent Person-days	2,417	3,592
Actual Person-days of Labour	11,964	14,171
Total Khara (absentee fines) Income (Rs.)	48,350	71,840
Income (Rs.)	134,8011	87,389
Expenditures (Rs.)	105,7715	29,034
(Overdue Payments) (Rs.)	11,270	23,745
Balance (Rs.)	29,030	58,354

Notes:
- "kulara" is a share system of apportioning both water supply (refer to Section 3.2.5.1) and labour requirements to each mauja.
- the number of kulahi could vary on each day it was called.
- kulahi records include labour for annual desilting of the main canal, construction of new structures, regular and emergency maintenance.
-khara (absentee fines) are collected by the Executive committee on the basis of Rs. 20 per person per absent day, individual maujas may elect to collect a higher fine and retain the balance in excess of Rs. 20 for their internal requirements.
- (The above information was obtained from written records maintained by the secretary and treasurer of the SMIS Executive Committee, 1989).
- labour contribution requirements are determined on the basis of the kulara system and is referred to as "Kulahi". One kulara is assigned to every 25 bighas of land (with a few exceptions). Thus, when single kulahi is called on a given day, one labourer must go to work for each kulara his or her mauja has.

Figure 3.3 Labourers carrying out annual main canal desilting

3.2.5 Use of the Water Resource

3.2.5.1 Water Allocation Principles

The SMIS has an established water allocation system which provides each mauja with their fair share of the available water supply. Water is allocated on the basis of kulara, with each kulara being the equivalent of one water share. If a mauja has 2 kulara of the present total of 93, that mauja is entitled to receive 2/93 or 2.15 per cent of the total available water supply. Thus the kulara system applies both to a mauja's requirement to provide labour and funds for the system's maintenance and development, and to its entitlement of water.

Most maujas' kulara was originally made on the basis of one kulara per 25 bigha of land (that is, one water share per 16.7 ha). However, as the SMIS has evolved some maujas' kulara allocation has been made higher relative to the land area due to higher water requirements. Farmers have thus adjusted the allocation of kulara over the years as they have gained experience with soil conditions (some areas experience very high rates of seepage and percolation) and other factors affecting crop water requirements (Pathak, personal communication, 1988).

Therefore the water allocation principle has not remained tied to land area for a particular mauja, but has been allowed to be adjusted by each mauja (with the consent of the others) according to their particular needs and their relative water delivery cost versus the maintenance cost to obtain it. In the SMIS, soil conditions (higher percolation losses) have required a higher water allocation proportionate to irrigated area, but farmers in the head areas are fortunate in that they have a lower cost of providing their mandatory (kulara) maintenance work because they are closer to the headworks. Farmers in the tail area have reduced their allocation because they experience much lower percolation losses and have a high water table, while their cost of providing maintenance service is much higher since they must travel long distances (up to 15-20 km) to work each day.

With the recent development of the Bhairawa Lumbini Groundwater Project (BLGWP) in the tail area of the SMIS, many maujas in that area have further reduced their number of kulara. As was mentioned earlier, these maujas are maintaining membership in the SMIS as an insurance policy in case their groundwater supply should fail. By maintaining membership with a minimal kulara allocation, these maujas could always increase their allocation by buying it back from the committee; but if they were to withdraw completely, re-entry into the system could be very difficult. Thus the total number of kulara has fallen from a high of 130 in the 1970's to the present level of 93.

This drop in the total number of kulara should theoretically mean that more water is available to those who remain, but farmers report that this has not occurred. As the number of kulara has decreased, so too has the total available water supply. Farmers believe that deforestation in the hills of the Tinau watershed has resulted in higher floods and lower base flows. Flows during the winter and spring months (the critical water shortage periods) have been particularly low in recent years. This has dampened the farmers confidence in planting second and especially third crops.

Some tail end maujas do not contribute labour (kulahi) to maintain the water supply during the dry season and consequently are not entitled to water during that period. The water supply during the dry season (spring) of 1989 was consequently apportioned to maujas comprising 83.5 kulara. There are several reasons for this practice:

i) land holding size is much larger in the tail and the incentive to cultivate second and third crops during the dry season is low;

ii) waterlogging occurs in some areas and farmers cannot get onto the land to till until long after rice harvest;

iii) the proportion of water lost by canal seepage is very high in the dry season when the available supply entering the system is reduced; and

iv) much work is required to deliver a very small amount of water. Sometimes the water does not even reach the tail areas.

During periods when the water supply is plentiful (throughout most of the monsoon season and early fall), water is delivered continuously or on demand to all maujas. The chief muktiyars adjust the width of the mauja canal inlet openings to achieve the water allocation entitled to each mauja. If a mauja does not require water for irrigation at any time it is required to close its inlet. Some mauja canal inlets have permanent concrete masonry structures whose openings have been set to abstract the allocated proportion of the total flow passing that point. When the available water supply becomes relatively scarce (usually in March through May), farmers adopt a strictly controlled 24 hour rotation schedule. The rotation schedule is established at a meeting of the chairman, chief muktiyars and the muktiyars from all the maujas who wish to receive water. If a muktiyar fails to attend the scheduling meeting, his mauja will lose its turn during that rotation.

The first delivery in the rotation schedule is always to the tail end maujas. This practise of starting at the tail end branch canal outlets and moving upstream over the ourse of the rotation cycle appears to have several benefits.

i) Delivery times are faster (immediate) to the next outlet upstream because as soon as the downstream mauja has completed its turn, the upstream mauja may open its outlet and divert all the main canal flow without any waiting period.

ii) Deliveries are also timed more equitably because there is no main canal delivery (lag) time required between maujas. If deliveries moved downstream, maujas would not receive equitable proportions of water during their time periods allocated because the distance between mauja outlets varies substantially.

iii) Such a delivery system also creates more equity in the amount of water actually delivered to the individual maujas since the amount of water available at the head of the main canal typically decreased over the rotation period, the tail end maujas will receive a higher volume of water (as measured at the head) per share which compensates to some degree for the high main canal seepage losses incurred in delivery the water to the tail end of the main canal.

iv) Those farmers who are farthest removed from the source of water supply are assured of receiving water, whereas, if they were last they may at times of water scarcity be exploited by head area farmers who may take a disproportionately large share, if not all, of the available water. By ensuring that tail area farmers receive water during the dry season the irrigation organization in turn ensures those farmers cooperation in operation and maintenance of the system.

Main canal conveyance efficiency is essentially the same whether the rotation cycle is from tail to head or vice versa.

The water allocation principle followed during a rotation schedule is six hours of total system flow per kulara. Smaller maujas who may not be able to accommodate the total available flow in their small canals, often combine their allotted period of time with several other adjacent maujas. This group of maujas then uses the water together during their combined periods. Some maujas where fields are far from the main canal inlet (such as Anandavan Madhuban) are allocated extra time in the rotation schedule to compensate for very long delivery times within the mauja. Other maujas are also entitled to extra time for filling ponds used for watering livestock. A few maujas are permitted to allow a little water to leak into their systems continuously for domestic (drinking and washing) purposes only, in areas (such as Dingernagar) where an alternate domestic water supply (such as standpipes or shallow wells) is not available.

Each mauja is responsible to police the main canal during their rotation period to prevent water theft. Maujas are also required to call kulahi from within their own mauja if they want to work in the Tinau river to try to divert more water into the main canal. The role of the chief muktiyars is to ensure that the rotation schedule is adhered to, although some flexibility is allowed if the other maujas agree to minor schedule changes that would ensure that all farmers receive at least some water.

When the available water supply becomes very scarce (typically from mid-April through May), the supply is only adequate for a small cropped area. This scarce water period corresponds with the third crop which is usually maize. Specifically, the water deliveries during this period come during the maturation of the early maize crop or the development of the late maize crop. Adequate water supply for either crop stage is critical. Therefore farmers do not plant large areas of maize as a third crop because of the high risk of losing the crop if April flows are particularly low and/or late May rains do not arrive on time. The chairman of the SMIS stated that there is no systematic means of determining the area which can be planted to maize. Farmers are allocated water on a per household basis for the maize (third) crop and must decide what area to plant based on past experience (Pathak, 1989). In Anandavan Madhuban mauja for example, each household receives one hour of water delivery. Therefore most farmers do not usually plant more than one bigha (0.67 ha) of maize, regardless of their total land area.

3.2.5.2 Water Distribution Infrastructure

The water distribution infrastructure consists of a large network of earth canals with a wide range of sizes. The largest, the Sorha mauja main canal extends 6.8 km south from the Taraprasad bhod regulator, ranges in width from 3 to 10 m, and has a flow capacity in its upper reaches of 15 m^3/s.

Some 30 canal inlets open off of the Sorha mauja main canal, two of which are located on the Sorha-Chhattis joint canal between Ita bhod and Taraprasad bhod. These 30 branch canals deliver water from the main canal to the command areas of the 33 maujas. Most (77%) of the inlets are constructed with poles, brushwood, stones and sand bags; while the others are of concrete or masonry construction and as such are more durable. The branch canals off the main canal feed areas of 17 to 267 ha and range in capacity from 50 to 600 l/s.

Within individual maujas, the branch canal may be further divided into sub-branch canals and farm ditches before water is ultimately delivered to the farmer's fields. In West Siddhanagar, the branch canal feeds into lateral farm ditches. In Anandavan Madhuban, the branch canal is divided into 5 large sub-branches and 3 small sub-branches. These sub-branches are further divided into farm ditches. Khopiya has 3 sub-branches off of the branch canal and fields are irrigated directly from the sub-branches and a few farm ditches.

Most canal turnouts do not have permanent structures, nevertheless farmers have constructed many structures as they have perceived the need. Structures built by farmers include: proportioning weirs, canal turn-outs, division boxes, bridges, culverts and aqueducts. Most of these structures are built with reinforced concrete and/or brick masonry. A few structures, particularly aqueducts, are wooden. Most canal divisions and turnouts are simply constructed with brushwood, stone and clay. Water may be blocked by packing clay mixed with straw and brushwood in an opening. Most permanent structures have slots for gate boards in each opening, but gates are seldom used because wood is expensive and is often stolen for firewood.

3.2.5.3 Irrigation Methods

The standard method of irrigating for all crops grown in the SMIS is basin flooding (refer to Figure 3.6). All the irrigated land is divided into small level plots which are surrounded by earthen dikes or bunds. Water is turned into the basin from the farm ditch by cutting an opening in the bund. Many farmers may irrigate from basin to basin as well. Basins are flooded as quickly as possible to obtain a uniform application of water, then the inlets (and outlets) are closed to pond the water so that it can infiltrate and replenish the soil. This method of irrigation is primarily used for rice cultivation, which requires the continuous ponding of standing water. Basin flooding is used to irrigate the other winter crops since the infrastructure for this method is already in place. Some farmers do change a few plots to furrow irrigation for cultivating vegetables during the winter.

3.2.6 Agriculture System

The existing system of agricultural production in Nepal is characterized by a high man-land ratio and a great disparity in land ownership; absentee ownership, high rentals and a system of share-cropping which inhibits the motivation of tenants; a large number of poorly fed livestock with low

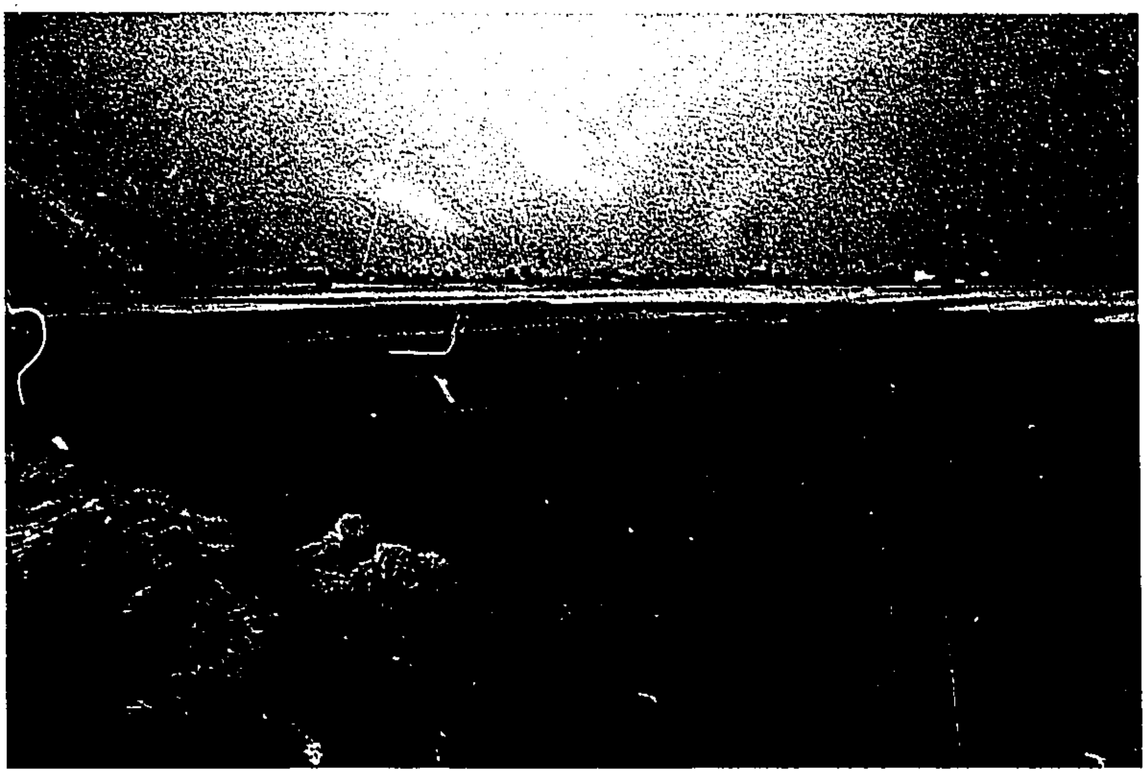


Figure 3.4 The standard method of irrigating - basin flooding

productivity and a declining forage base, deterioration of the environment and decreased soil fertility; ineffective extension services; a lack of timely availability of externally sources of inputs; and scarcity of institutional credit for tenants and small farmers. (ADB, 1982 and Pradhan, 1985).

Terai agriculture produces over 80 per cent of Nepal's rice production, which in turn accounts for 55 per cent of total food grain production. Cereals (food grains) are grown on over 80 per cent of the land, with the remainder under cash crop cultivation. The average Terai farm holding is 2.13 hectares in size, and although conditions are favourable, agriculture in the Terai is still subsistence for the most part. Most farmers rely on rain-fed water supply during the monsoon season. Only 20 per cent of the Terai's cultivated land is cropped in the winter, and little more than 4 per cent receives reliable irrigation year round. Annual cropping intensities range from less then 100 to 140 per cent typically, but may well exceed 200 per cent with reliable irrigation (EIU, 1986).

It is important to note that the term "crop intensity" typically used in Nepal and elsewhere is expressed in percentage terms. The crop intensity for a farm where all cultivable land (100%) was cultivated to monsoon (season 1) crops, 90% was cultivated to winter (season 2) crops, and 50% was cultivated to spring (season 3) crops would be 240%. Such use of a percentage basis may be incorrect and therefore an index termed the Crop Intensity Ratio (CIR) has been defined and applied for this analysis (refer to Section 4.4.1).

Given this background, the agriculture system of the SMIS contrasts in many respects with the typical conditions in the Terai. Generally, the SMIS agriculture system is dynamic and productive, with the advantages of a well-serviced location and a rich land base.

3.2.6.1 Land Use

Of the estimated 1500 ha total command area (CA) of the SMIS (estimated from aerial photography), approximately 75 % is cultivated and receives irrigation water from the SMIS. The remaining 25% of the CA is taken by housing, roads and paths, canals and canal right-of-ways, commercial and industrial developments, schools, government offices, temples, non-arable land and natural drainage channels. There is no room for the expansion of cultivation in the SMIS CA.

The average landholding size in the SMIS is 0.70 ha, estimated from the intensive study areas. Table 3.2 shows that landholding size varies significantly within each mauja, and

Table 3.2 Land use in the SMIS

Branch Area	Total Area (ha)	Cult. Area		Number of Farms	Owners		Tenants	
		(ha)	(%)		(No.)	(%)	(No.)	(%)
WS	12.28	10.86	88	32	26	81	6	19
AM 10	14.63	3.57	93	23	19	83	4	17
AM 7	4.69	4.18	89	5	3	60	2	40
Khopiya	16.65	15.38	92	9	8	89	1	11
Totals	48.26	43.99	91	69	56	81	13	19

Note:

Average Landholding = 0.70 ha

that the average landholding size increases from the head to the tail part of the system. Farmers in the tail areas generally have poorer quality land (in terms of drainage and fertility) and thus their larger landholdings tend to compensate for their less intensive cropping system. A few farmers (who are typically long term residents) throughout the SMIS have large landholdings.

An estimated 87 per cent of farmers are landowners, while 19 per cent are tenants. Some farmers with small landholdings also cultivate other parcels of land under a tenant relationship. Typically a tenant farmer arrangement allocates 50 per cent of the crop production to the landlord.

Crops are grown throughout the year in the SMIS, with cropping intensities varying mainly according to the season and the location within the system. In general it may be said that the SMIS CA is under intensive land use for the production of irrigated crops. Cropping intensity data is presented in Section 5.5.

The population of the SMIS is estimated to be 8,500 persons. Population may also vary somewhat through the year due to the movement of farm labourers, and due to the migration of local residents to find other employment.

3.2.6.2 Crops

Monsoon paddy (rice) is the most important crop to SMIS farmers. It is transplanted from seedbeds in June or July as soon as the available (rain and irrigation) water supply is adequate to maintain ponded water in the paddys (fields). Rice is harvested in October and November. In the winter, wheat, mustard (oilseed) or lentils are the principal second crops. These crops are sown following the rice harvest, and are harvested in February through April.

Many farmers try to plant a third crop on some of their land in the spring. The third crop of choice is maize (corn), which is harvested in May through July. Vegetables and fruits are also grown year round. A number of improved (high yielding) varieties are used, particulary for rice and wheat.

3.2.6.3 Soil Characteristics

The soil parent material ranges from coarse to predominantly fine alluvium throughout the system. Soil textures are mostly silty loam and silty clay loam. The only significant variation in soil characteristics through the system is in the drainage characteristics. Soils in the head and most middle areas of the system are well drained, but moving south from the middle to the system's tail areas drainage is poor and waterlogging is a problem. Tahal (1988) conducted several detailed soil surveys in the area, while general land and soil classifications are reported by Kenting (1986) in their Land Resource Mapping Project (LRMP).

Manual soil texture analysis in the study areas confirmed that the predominant soil fractions of the uppermost soil horizon were silt and clay. Laboratory analysis of some samples taken in similar areas of the CMIS indicated the top soils were all silts.

3.2.6.4 Farming Practices

Cultivation of crops is very labour intensive in the SMIS with a limited degree of mechanization. Most farmers plough their fields with a simple wooden plough drawn by a team of two water buffalo or oxen, and levelling is accomplished using a planer board. A few farmers own small tractors with ploughs and these are often hired on a hourly basis by farmers who can afford them.

Seeding (of crops other than rice which is transplanted) is done by hand, usually by someone who follows the plough.

Crops are harvested by hand using a hand scythe.

Threshing is usually carried out by hand as well. However some farmers rent threshing machines. Small portable threshers driven by a small diesel engine are available, as well as a few large threshers that are driven by a tractor power take off (PTO). Winnowing is done manually often with the aid of a hand powered fan.

CHAPTER 4

RESEARCH METHODOLOGY

Data and information collection consisted primarily of regular daily recording of physical measurements and observation of irrigation related activities in the irrigation system. Two Nepalese research assistants were trained to assist with data collection and language translation. Data was recorded in field notebooks and on daily data collection forms. Observations were recorded in notebooks, and photographs and video footage were also taken.

Data and information was collected over a very extensive period of ten months, from October 1988 through July 1989. During the first three months that the author was in Nepal (May through August 1988) assistance was given to IIMI in the establishment of its terai FMIS research project in the neighbouring CMIS. In September the SMIS was selected for study. During October through December, the research methodology was devised and the necessary structures for physical data collection were constructed and installed in the field. Daily data collection was thus able to commence in December 1988. Although the author departed Nepal in May 1989, data collection continued by the research assistants through July under the supervision of IIMI staff.

4.1 Climate

Climatological data was required in order to determine the crop water requirements of each crop grown, as well as to establish the particular set of constraints to crop production due to the effect of climatic conditions on the available water supply for irrigation. The various data (described below) is summarized in Section 5.3.

4.1.1 Rainfall

Rainfall was recorded daily at three sites in the study area. Raingauges were installed at West Siddhanagar, Shankar Nagar (at the office) and Jodeni (Anandavan Madhuban). Monthly rainfall records from 1971 through May 1989 were also obtained from the National Wheat Development Programme research station north of Bhairawa (15 km south of the study area).

Monthly precipitation records for the study period are compiled in Table 4.1, and historical rainfall data from the Bhairawa station is also included for comparison.

Actual rainfall values are modified in order to reflect the portion of rainfall which is actually utilised by the crop(s) before being used in the water balance equation to determine irrigation water requirements (IWR) (refer to Section 4.2.4). These modified values are referred to as effective rainfall (or effective precipitation). Effective rainfall is defined by the FAO as "that which is useful or usable in any phase of crop production" (ASAE, 1983). Therefore <u>effective rainfall</u> includes rainfall intercepted by living or dry vegetation, lost by evaporation from the soil surface, lost by evapotranspiration during growth, that fraction which contributes to leaching, or facilitates other cultural operations, either before or after sowing without any harm to yield and quality of the principal crops. Consequently, <u>ineffective rainfall</u> is that portion which is

Table 4.1 Monthly precipitation records (Study period, December 1988 - June 1989)

MONTH	MEASURED RAINFALL[1] (mm)	EFFECTIVE RAINFALL[2] (mm)	HISTORICAL AVERAGE RAINFALL[3] (mm)
January	32	27	12
February	3	0	11
March	32	28	14
April	0	0	20
May	80	76	49
June	369	330	257
July	912	894	452
August	-	-	293
September	-	-	287
October	-	-	77
November	-	-	4
December	36	32	12
Total Annual	-	-	1488

Notes:

[1] average measurements at three sites within the SMIS
[2] calculated (refer to Section 4.1.1)
[3] mean monthly rainfall (1971-1989) measured at the Bhairahwa agriculture station with the probability of 80% (equal or more)

lost by surface run-off, unnecessary deep percolation losses, the moisture remaining in the soil after the harvest of the crop which is not useful for the next season's crop. Therefore, factors that influence effective rainfall include: rainfall characteristics land slope, soil characteristics, ground water characteristics, water management practices, crop characteristics, carry-over soil moisture, surface and sub-surface in and outflows, and deep percolation (Misra and Ahmed, 1987). An extensive review of models for estimating effective rainfall has been published by the Food and Agriculture Organization (FAO, 1974).

Precise evaluation of effective rainfall involves the measurement of rainfall, irrigation water deliveries, surface runoff losses, percolation below the root zone and soil moisture use by crops. Given the complexity of such measurements empirical criteria have been developed for taking effective rainfall into consideration in irrigation system planning and operation. These empirical criteria generally use a percentage of the total or dependable rainfall. Dependable rainfall (used for planning) is taken as the monthly rainfall, P_{80}, which is exceeded 80% of the time. The P_{80} amounts are determined from historical rainfall data by applying the 80% probable average annual rainfall ratio to the average monthly rainfall amounts.

Using discrete intervals (such as half-month) for interpolating the corresponding P_{80} rainfall amounts, the effective rainfall (Pe) is calculated by the following criteria for monsoon rice crops (FAO, 1977):

If P_{80} < 5m,	Pe = 0	(4.1)
If 5mm < $P_{80} \leq$ 10mm,	Pe = P_{80}	(4.2)
If 10mm < $P_{80} \leq$ 100mm,	Pe = 0.85 P_{80}, or [(ET crop) + percolation losses] (whichever is less)	(4.3)
If P_{80} > 100mm,	Pe = 0.70 P_{80} or [(ET crop) + percolation losses] (whichever is less)	(4.4)

For non-rice crops growing outside the monsoon season, rainfall is a relatively minor contribution to water requirements. As such, there is little value in estimating the contribution with great precision and the following relationship is recommended:

$$P_e = 0.70\ P_{80} \qquad (4.5)$$

where:

P_e is the effective rainfall, and

P_{80} is the rainfall with 80% exceedance level.

(Sir M. MacDonald, 1988)

In this study effective rainfall was calculated using modified empirical criteria from the daily measured records for the study period. Records of effective rainfall as used by Tahal (1988) from Bhairawa Agricultural Station data were also used.

4.1.2 Other Climate Data

Descriptive information regarding the weather was recorded daily. The relative proportions of sunlight and cloud, together with a qualitative estimation of wind speed were observed. These qualitative daily records were used to verify the data used to calculate evapotranspiration (ET), and to define the variables and parameters used in the calculation methods.

The following data was available from the Bhairawa Agriculture Station as reported by Tahal (1988):

- Monthly mean daily temperatures, for the years 1971 through 1987;
- Monthly mean relative humidity, for the years 1971 through 1987;
- Monthly mean daily sunshine hours, for the years 1985 and 1986;
- Monthly mean wind velocities, for the years 1985 and 1986.

This data is used in calculating ET by the Penman method.

4.1.3 Evapotranspiration

Evapotranspiration (ET) is the combined process by which water is transferred from the earth's surface to the atmosphere. The ET term in the water balance equation (refer to Section 4.2.3) reflects the water leaving the soil and plant surfaces by direct evaporation and by transpiration through the plant (crop) tissues. The ET "losses" are necessary for crop development, thus ET is typically equated with the term "consumptive use" (CU) and ET is generally taken to represent the water requirements of crops.

Reference crop evapotranspiration (ET_o) must be calculated to determine crop water requirements (CWR). ET_o accounts for the effect of climate on CWR and is defined by the FAO (1977) as "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground, and not short of water". ET_o values for this study were obtained through direct field measurements of an evaporation pan, and by calculating ET_o values using standard empirical methods with meteorological data.

4.1.3.1 Direct Field Measurement of ET

The principal methods for direct measurement of (actual) ET are:

i) by use of a lysimeter, which is a large container of soil set in the field to represent the prevailing soil and climatic conditions of a crop and to allow more accurate measurement of ET (and seepage and percolation) than can be carried out in the field itself,

ii) by field experimental plot,

iii) by soil moisture depletion studies,

iv) by the water balance equation, and

v) by pan evaporation.

The first three of the above methods require sophisticated research in their own right and were not well-suited to use in this study, while the water balance equation has two unknowns, ET and seepage and percolation (S&P), and consequently is not readily solved.

Evaporimeters (or evaporation pans) are one of the simplest tools for determining ET_o in the field and have been found to provide reasonably accurate results. A U.S. Weather Service Class A evaporation pan was installed and maintained during this study. When properly installed the evaporation pan gives an indication of the integrated effect of radiation, wind, temperature, and humidity on evaporation from an open water surface. Pan evaporation values are subsequently multiplied by a correction factor (K_{pan}) to produce the ET_o values. K_{pan} accounts for the particular combination of environmental conditions at the pan location and K_{pan} values generally range between 0.7 to 0.85. The pan evaporation method thus gives the reference crop evapotranspiration (ET_o) as:

$$ET_o = K_{pan} * E_{pan} \tag{4.6}$$

where:

K_{pan} = the dimensionless pan coefficient which depends on local environmental conditions,

E_{pan} = pan evaporation (mm/day). (ASAE, 1983)

The daily rate of actual ET from a crop will usually be less than the ET_o, but may occasionally exceed ET_o. Canopy characteristics, stand density, stage of growth, degree of surface cover, and especially the moisture regime (whether wet or relatively dry), all effect ET. The ET_o can be assumed to be in the neighbourhood of the peak ET rate on the seasonal curve.

4.1.3.2 Calculation of ET_o

The common alternative to measuring actual ET is to calculate the reference crop evapotranspiration (ET_o) for the crop. ET_o is also referred to by some as the maximum or potential evapotranspiration (PET). The concept of PET is an attempt to characterize the climatic environment in terms of its evaporative nower. Penman (1956, as quoted in Hillel, 1987) defined PET as "the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water." Thus the definitions of ET_o and PET are equivalent. There are various empirical methods for estimating ET_o, all of which are based on climatic factors, with varying degrees of relative complexity.

Two sets of ET_o values were used in this study: (i) averages of calculated monthly values according to the Blaney-Criddle, Radiation and Penman methods as reported by Tahal (1988), and (ii) monthly adjusted E_{pan} values for the study period. All the ET_o data is included in Section 5.3. A comprehensive description of the methods for determining ET_o may be found in the FAO Irrigation and Drainage Paper No. 24 - Crop Water Requirements (1977). These methods are reiterated for the Nepalese context in the WECS Technical Guideline No. 1 (1985).

4.2 Crop Water Requirements

Crop water requirements (CWR) are defined as "the depth of water needed to meet the water loss through evapotranspiration of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment" (FAO, 1977). Thus CWR values are often termed ET_{crop} values. The calculation of CWR must take into account the effects of climate, crop characteristics and local conditions and practices. The accuracy of its determination depends largely on the type and quality of the climatic data available and on the accuracy of the method used to estimate ET_o. (WECS, 1985)

The calculation of CWR involves four steps as follows:

i) calculation of ET_o,

ii) selection of the appropriate crop coefficients (Kc),

iii) calculation of ET_{crop}, and

iv) consideration of the effects of local climatic conditions and agricultural practices on ET_{crop} and adjustment of the final CWR values accordingly.

4.2.1 Crop Coefficients

The crop coefficient (K_c) is defined as "the ratio between crop evapotranspiration (ET_{crop}) and the reference crop evapotranspiration (ET_o) when both apply to large fields under optimum growing conditions" (FAO, 1977). The crop coefficient is not only specific for each crop, but is also a function of the phenological (growth) stage of the crop. Transpiration of a crop increases in response to increases in the leaf area of the canopy. At sowing, the crop coefficient will be a fraction of the reference evapotranspiration, and the coefficient will increase after emergence, slowly at first. The rate of increase will be most rapid during the vegetative phase of the crop and will level off to values close to 1.0 when the crop has reached the stage of a closed and uniform cover (WECS, 1985).

The water requirement at the full canopy stage will be equal to or slightly above ET_o. Towards ripening, the crop coefficient may drop as the leaves approach senescence and are no longer actively transpiring. Cultivated crops, particularly annual crops, pass through several stages from emergence until maturity (WECS, 1985).

The FAO (1977) recognizes four development stages:

i) <u>Initial Stage:</u> Sowing to fruit emergence with the soil surface hardly covered by the crop (ground cover <10%).

ii) Development stage: Emergence to effective full ground cover (ground cover - 70 to 80%). The Kc values increase to about 0.70.

iii) Mid-Season Stage: Effective full ground cover to full flowering (cereals) or to post formation (indicated by the discolouring of leaves, legumes). The K_c values reach their peak values (1.05 for maize, 1.0 for sorghum, 1.10 for wheat).

iv) Late-Season Stage: full flowering (post formation) to harvest or maturity. In the case of grain (cereals) K_c values may drop to around 0.8 or less (wheat).

The steps in deriving K_c values and the resultant crop curves are outlined in the FAO guidelines (1977). The K_c values calculated for use in this study are given in Section 5.3.

4.2.2 Crop Evapotranspiration

The evapotranspiration of the crop (ET_{crop}) is usually the principal factor in determining the CWR. ET_{crop} is calculated by:

$$CWR = K_c * ET_o \tag{4.7}$$

where:

K_c= the crop coefficient for the particular growth stage.

However, the values of ET_{crop} reflect the evapotranspiration of a disease-free crop, grown in very large fields, not short of water and fertilizers. Actual ET_{crop} will depend on local factors which may include:

- climatic variations within the area for which the climatic data is applied,
- growing season,
- the level of available soil water in the root,
- groundwater levels in or near the root zone,
- soil salinity,
- sensitivity of crops to irrigation timing and water stress,
- crop development,
- method of irrigation, and
- agricultural practices (such as use of fertilizers, plant density, tillage, etc.). (FAO, 1977.)

Monthly ET_{crop} values for each crop over its particular growing season are provided in Section 5.3.

4.2.3 Net Irrigation Requirements

The net irrigation requirements of crops (IR_{net}) are calculated by the field water balance equation:

$$IR_{net} = ET_{crop} - (P_e + G_e + W_b)$$
$$= (\text{losses}) - (\text{gains}) \qquad (4.8)$$

where:

P_e = effective rainfall (mm),

G_e = groundwater contribution (mm),

W_b = stored soil water at the beginning of each period (mm).

All variables are expressed in units of depth of water (mm) and, depending of the level of accuracy required, IR_{net} can be determined for seasonal, monthly or shorter irrigation periods. The sum of IR_{net} for the different crops grown over the entire irrigated area forms the basis for determining the necessary water supply (FAO, 1977).

4.2.4 Irrigation Water Requirements

In addition to meeting the net irrigation requirements, water may be required for:

i) leaching accumulated salt from the root zone,

ii) cultural practices such as land preparation, rodent control, etc.,

iii) conveyance and application (efficiency) losses.

Thus the overall irrigation water requirements (IWR) can be determined (in m^3/month) from:

$$IWR=\frac{10}{E_p}\left[\sum_i\left(\frac{A\times IR_{net}}{1-LR}\right)_i\right] \tag{4.9}$$

where:

E_p = overall system irrigation efficiency fraction,

A = area under a given crop (ha),

IR_{net} = net irrigation requirements of a given crop (mm/month), CWR or ET_{crop},

LR = leaching requirements fraction.

i = number of crop seasons. (FAO, 1977)

Water requirements for cultural practices are typically one-time applications and may be added to the IWR in the particular month in which they occur. Tables of IWR values calculated for each crop grown during the study period are included in Section 5.3.

4.3 Water Supply and Deliveries

4.3.1 Source

Systematic measurement of the available water supply in the Tinau river was not possible due to the absence of either an operational gauging station or a suitable control section where calibration could be carried out. A gauging station was once maintained in the Tinau gorge above Butwal during the 1960's which was operated by the Department of Irrigation, Hydrology and Meteorology (DIHM). The average monthly flows are illustrated in Figure 4.1 for the period for which data was recorded. There are extreme variations in flow through the year with the dry season discharge as low as 3 m^3/s, while two recent floods have been estimated to carry several thousand cumecs (Yoder, personal communication, 1989).

A sample flow metering was carried out during a period of low (dry season) flow (May, 1989) in a reasonably uniform reach of the river upstream from the Butwal bazaar in the Tinau gorge. The measured flow was approximately 2 m^3/s, compared with 0.5 m^3/s that was being diverted into the combined Sorha-Chhattis irrigation canal - a proportion of

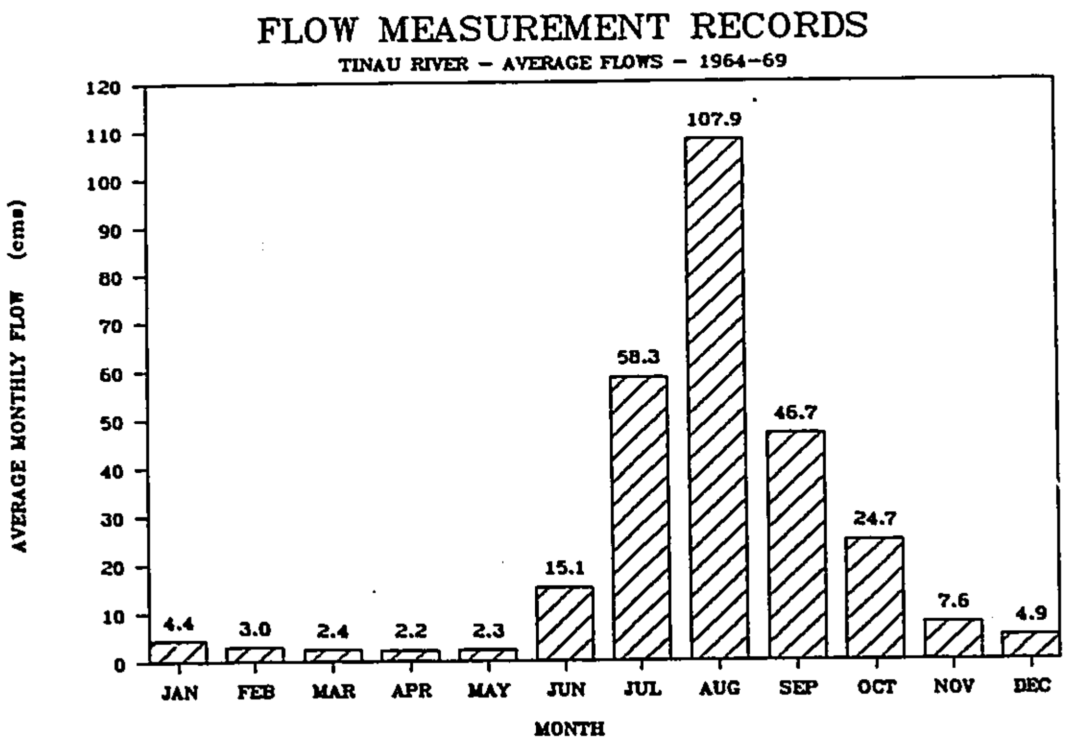


Figure 4.1 Average monthly flows in the Tinau River at Butwal (1964-69)

approximately 25% of the available supply in the Tinau at that time.

4.3.2 System Water Delivery

The existing Taraprasad Bhod division structure was chosen as an ideal site for measuring the total water delivery available to both the SMIS and the CMIS. The division structure has the following characteristics as illustrated in Figures 4.2 and 4.3:

- a gravel bottom approach channel with vertical, stepped gabion side walls;
- a concrete cut-off wall whose rounded upstream edge rises slightly above the upstream bed level, and the sill (top) of the cut-off wall is smooth, wide and level;
- a wall divides the sill and extends downstream, and thus divides the total flow proportionally between the two systems, with 40.6 percent of the flow allocated to Sorha mauja and 59.4 percent of the flow allocated to Chhattis mauja;
- the water falls over the downstream edge of the sill into two stilling pools on each side of the dividing wall, from which it flows downstream in the respective Sorha and Chhattis mauja main canals;

Figure 4.2 Taraprasad bhod division structure (upstream, facing downstream)

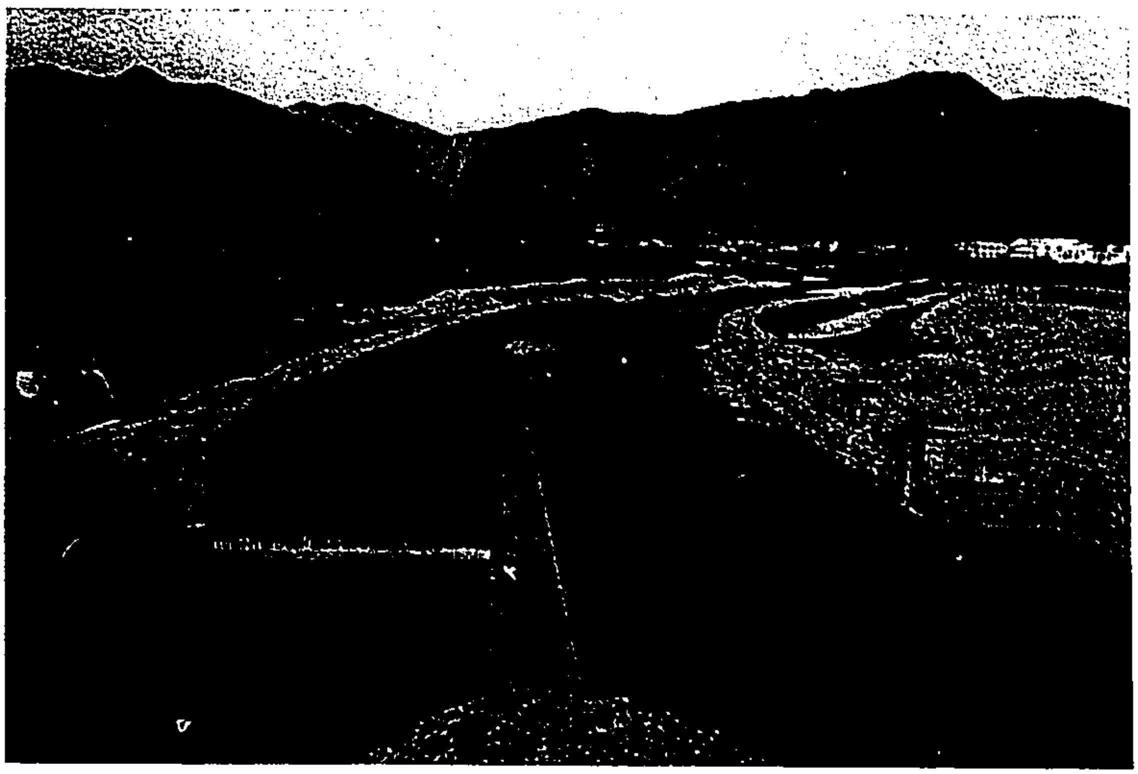


Figure 4.3 Taraprasad bhod division structure (downstream, facing upstream)

- the height of the sill crest above the stilling pool bed level is sufficient to facilitate free discharge of the nappe except during exceptionally high flows, or when the downstream bed level rises to near the crest level due to heavy sediment deposition, at which time the flow over the sill may become partially submerged.

In hydraulic terms therefore, the structure functions like a broad-crested weir - with vertical faces, a smooth, slightly inclined, wide (broad) crest, slightly rounded upstream and sharp right-angled downstream corners, and critical flow occurring over the sill.

For weirs discharging freely, the broad-crested weir formula is given (in metric terms) as:

$$Q = M * B * H^{1.5} \qquad (4.10)$$

where:

Q = the discharge in (m^3/s),

M = the metric broad-crested weir coefficient, which combines the discharge coefficient and the factor $\sqrt{2g}$ from the original equation (Simon, 1986),

B = the width of the weir opening in (m),

H = the sill referenced upstream water depth. If the velocity of approach is sufficiently low as to render the velocity head negligible, the energy head is accurately represented by H.

A fixed relation may thus be developed by determining the weir coefficient for a particular broad-crested weir, having a sufficiently wide crest so that the nappe assumes only one form over the range of flows measured. According to values tabulated by Simon (1986) the coefficient, M, for this structure should be in the range of 1.45 to 1.55. However, since the approach velocities are high (ranging from 0.10 to 1.25 m/s) due to the shallow nature of the approach channel, and since the sill is slightly inclined so as to overcome friction losses, calibration of the structure was required to determine a unique coefficient which holds over the range of discharges measured.

Calibration of the structure was achieved by computing the total stream flow upstream of the structure by flow metering at depths corresponding to a range of sill referenced head values. The Valeport BFM002 miniature current flow meter (propeller type) was used to measure stream velocity, with an operating range of 0.03 to 5.0 metres/sec at better than 1.5 percent accuracy. The flow metering station was established three metres upstream of the division structure in a uniform, straight section of the approach channel. Mean velocity measurements were made at a depth of 0.6 of the water depth at that point from the water surface (for water depths less than 0.6 m, USBR, 1984), at about 20 points across the width of the channel cross-section at regular intervals of 0.5 to 0.6 metres of the channel width.

Linear regression analysis was applied to the flow metering data to determine the relationship between two variables by providing a mean line which best indicates the trend of the coordinates on a graph. Regression analysis employs the method of least squares to minimize the total divergence of the points from the line. Computer analysis of the flow versus head data (using Lotus 1-2-3® regression functions) determined a high degree of correlation between the two variables and produced the value of the coefficient M for the structure of 2.02. The resulting rating curve for the Taraprasad division structure is shown in Figure 4.4.

A survey was carried out to determine the average plane level of the sill crest, and to then reference it to several secure benchmarks. The upstream head over the crest was initially measured twice daily, by measuring the distance to the water surface from a benchmark at the side of the channel. This system of manual measurement was replaced with an automatic recording system. A computer data logger was installed which recorded channel water depth (and thus sill referenced head) at regular (10 minute) intervals by means of an ultra-sonic

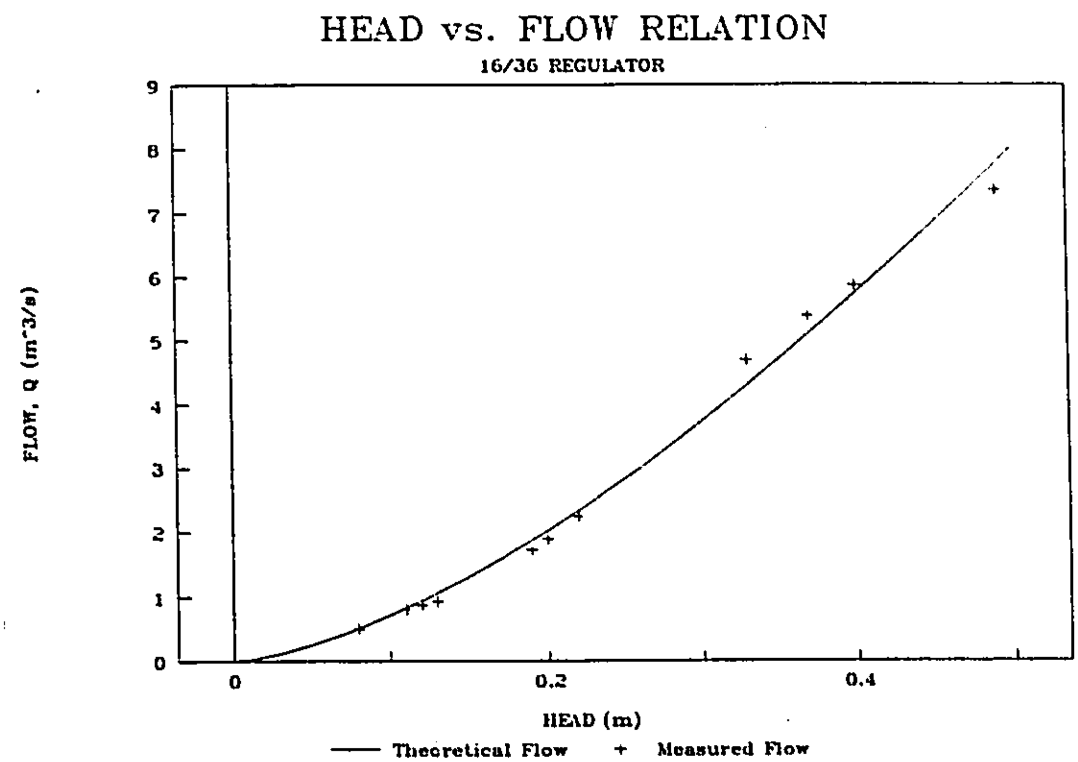


Figure 4.4 Flow rating for the Taraprasad bhod division structure

depth sensor installed in the bottom of a stilling well at the side of the channel. These recorded values were checked regularly with manual measurements, and were transferred from the datalogger in the field using a portable computer every two weeks.

Water depth measurements by the datalogger were stored in ASCII files in the computer, and were subsequently transferred to Lotus 1-2-3® spreadsheet files for analysis. Depth measurements were averaged over two hour intervals, converted to head readings, and finally applied to equation 4.10 to produce the flow and water delivery volume data. SMIS water delivery data is summarized graphically in Appendix A.

4.3.3 Branch Canal Water Delivery

Water deliveries were measured to the three branch canal systems which were selected for intensive study. A flow measurement structure was designed, constructed and installed in each of three canals near the inlet from the main canal. Design of these structures was difficult since there was no accurate means of determining the range of flows that the structures would be required to handle, and farmers were very sensitive to any disturbance of the flow regime in their canals that they might perceive to alter their water allocation.

A "RBC" (Replogle, Bos, and Clemens, 1984) long-throated portable sheet metal flume (refer to Figure 4.5) was installed at West Siddhanagar (WS). The RBC flume was designed using a computer modelling program (Bell, 1988) which also produced a rating table (head versus flow relationship) for each design. The WS inlet (WS_{in}) flume could measure flows from 2 to 70 l/s with an accuracy of $\pm$ 2%. The other major advantages of this type of flow measuring structures was that it created a minimal backwater effect (of approximately 14 mm at full flow) and provided accurate results even with downstream submergence values exceeding 90%.

Head readings were taken manually twice per day in WS, and more frequently (every half hour) during irrigation periods. The WS_{in} flume was equipped with a stilling well so that a datalogger could be used for recording head during periods of intensive irrigation. The flume's flow measurement records are summarized in Appendix A.

The much larger Anandavan Madhuban (AM) main branch canal required a structure with a high discharge capacity. Fortunately, a survey of the canal bed revealed a significant slope downstream from the canal inlet. This feature permitted the installation of a large rectangular sharp-crested weir

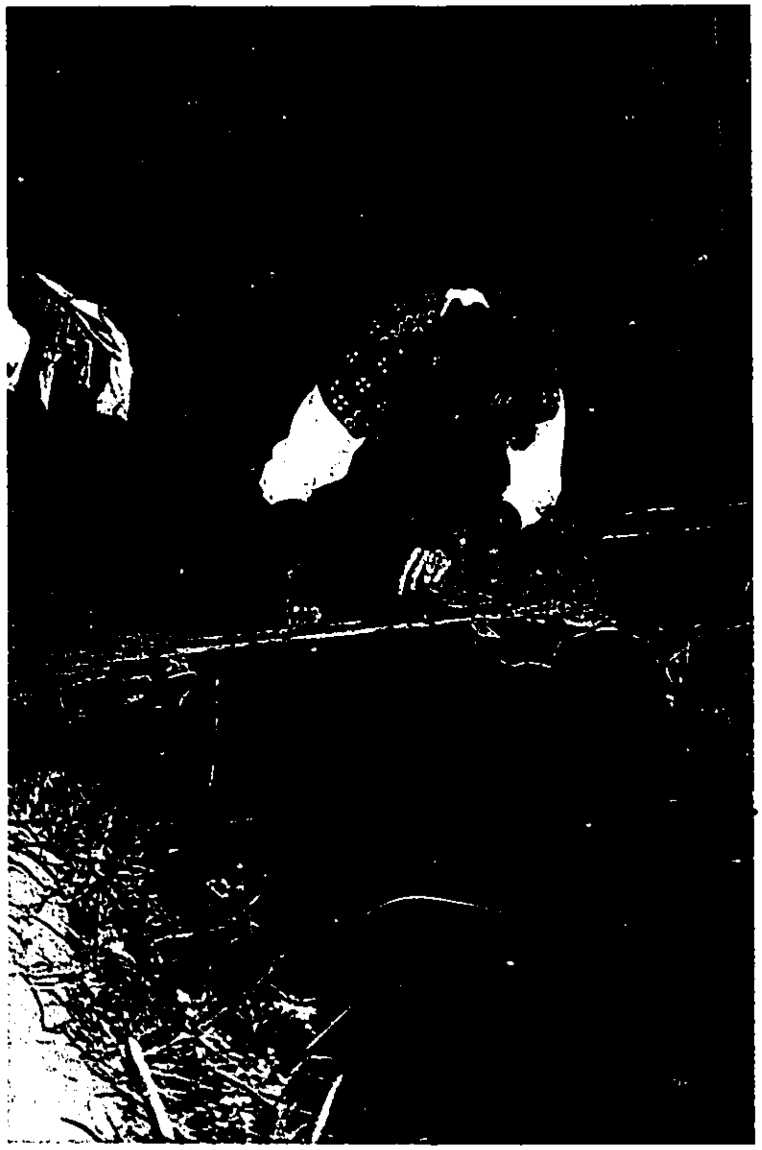


Figure 4.5 West Siddhanagar inlet flume

(refer to Figure 4.6). The weir was constructed with wood and sharp metal strips were attached along the sides and crest of the openings. The structure failed shortly after its first installation due to seepage and was re-installed with a sheet metal barrier buried to a depth of 2 m below the canal bed and 1 m into the canal banks. Rip rap provided downstream erosion protection.

A staff gauge and stilling well were installed in the upstream pool. Head measurements were taken twice daily, and more frequently during irrigation. A datalogger was also installed at this structure for continuous recording during intensive irrigation periods (during the water rotation schedule). The AM inlet weir was capable of measuring flows of up to 450 l/s and in one instance withstood flood flows estimated to be 650 l/s which over-topped the structure. The weir's flow measurement records are included in Appendix A.

A brick masonry broad-crested weir with a rectangular section was designed using the computer modelling program (Bell, 1988) and constructed in the Khopiya branch (refer to Figure 4.7). This structure was designed according to criteria established by Clemmens et al. (1988), and is similar in its characteristics to the RBC flume. The Khopiya weir was capable of measuring flows in the range of 2 to 100 l/s. The weir's flow measurement records are summarized in Appendix A.

Figure 4.6 Anandavan Madhuban main weir

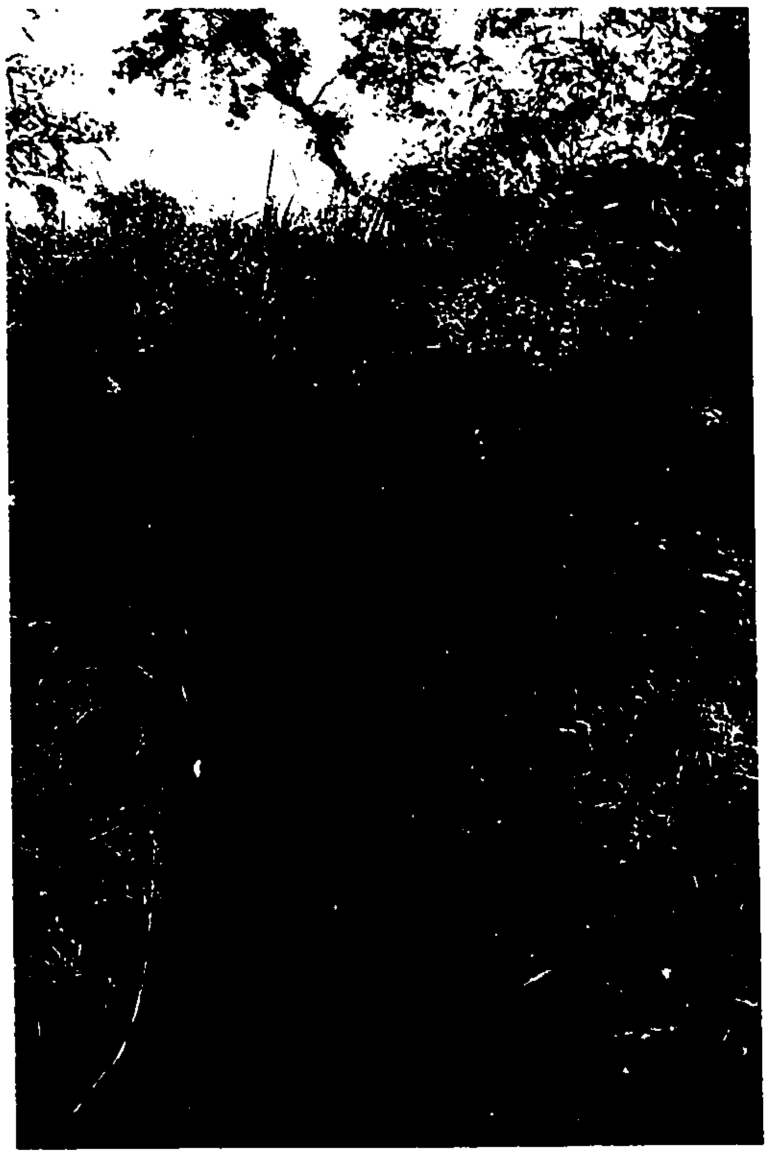


Figure 4.7 Khopiya flume

During water scarce periods when a water rotation schedule was followed from branch to branch, the delivery times to each branch system were also recorded and are included in Section 5.2.

4.3.4 Sub-branch and Farm Water Deliveries

Flows in selected sub-branches and farm ditches (near farm field inlets) within the West Siddhanagar (WS) and Anandavan Madhuban (AM) areas, were also measured using sharp-crested rectangular weirs and RBC flumes. These measurements were used to determine the amount of water that was actually delivered to the field for irrigation, and to determine canal conveyance efficiencies at that particular level of the distribution infrastructure.

In West Siddhanagar, two RBC flumes were installed in the branch canal, one in the middle (WS_{mid}) and one at the tail (WS_{out}) where any excess or unused flow was drained to another branch canal. These flumes provided accurate measurements of irrigation deliveries to individual farmers, the proportion of water actually used for irrigation, and the proportion of water lost to canal seepage and percolation. In Anandavan Madhuban, two sharp-crested rectangular weirs were installed, one at the inlet to the second sub-branch area (AM_{10}), and one at the inlet to the fifth sub-branch area

(AM_{12}). Two RBC flumes were installed in the "7 bigha" sub-branch area ($7B_1$ and $7B_2$). These structures provided measurements of irrigation deliveries to farmers and the proportion of water actually delivered to sub-areas within the large AM system. Canal conveyance losses were also determined from this data.

Details of each individual irrigation event were recorded for all 31 farmers in West Siddhanagar, the 23 farmers served by the second AM sub-branch, the 5 farmers served by the AM "7 bigha" sub-branch, and the 9 farmers in Khopiya. Altogether, the irrigation activities of 68 farmers were monitored.

Data collected was compiled for each of these four areas in "irrigation" files which included the following information: date, farmer, inlet number, crop(s) irrigated, area irrigated, starting and stopping time of irrigation, duration of the water delivery, average flow rate, resultant application depth, crop growth stage, percentage of seasonal crop water requirements provided, and a note about the farmer's perception of the adequacy and timeliness of the water supply. Irrigation data and information files are compiled in Appendix B.

4.3.5 Canal Conveyance Efficiency

Flow measurement data was also utilized to calculate canal conveyance efficiencies for the various levels of the canal system infrastructure. In irrigation systems such as the SMIS with earth canals, a considerable proportion of the total flow entering a particular reach of canal may be lost before the water is finally delivered downstream. Causes of canal leakage include:

- divisions of water from canals without adequate control structures,
- branch canal capacity insufficient for high flows during rotational water deliveries,
- rodent holes,
- seepage and percolation,
- evaporation,
- water theft and domestic use, and
- gates not properly sealed.

The following sections of canal were used to evaluate conveyance losses, (refer to Figure 3.1, back pocket):

i) main canal, from Taraprasad bhod to the AM main branch inlet weir;

ii) WS branch, from WS_{in} flume to WS_{mid} and/or WS_{out} flume(s);

iii) AM first sub-branch, from AM main weir to a temporary weir in a division box at Nyamil road;

iv) AM main branch, from AM main weir to AM_{12} weir and/or AM_{10} weir.

Thus canal conveyance losses in the main, large branch and small branch canals could be determined.

The inflow-outflow method was used to calculate seepage losses. This method requires the installation of flow measurement devices at the head and tail of a canal section to determine the volume of water flowing into and out of the section. The difference between the two measurements is the total conveyance water loss, given as V_L in volumetric terms (m^3) over a given period of time:

$$V_L = V_{in} - V_{out} \tag{4.11}$$

where:

V_{in} = the volumetric inflow

V_{out} = the volumetric outflow

Conveyance loss can also be expressed in percentage terms as:

$$V_L(\%) = \frac{V_L}{V_{in}} x100 \frac{(V_{in}-V_{out})}{V_{in}} x100 \qquad (4.12)$$

or as a delivery or conveyance efficiency, E_d:

$$E_d(\%) = \frac{V_{out}}{V_{in}} x100 = 1 - V_L(\%) \qquad (4.13)$$

During conveyance loss trials where inflows are at a fairly constant rate, water loss volumes can be expressed in terms of steady state or constant flow rates:

$$Q_L = Q_{in} - Q_{out} \qquad (4.14)$$

where:

Q_{in} and Q_{out} = the inflow and outflow rates respectively (in l/s)

Q_L = the steady state flow loss (l/s)

In order to compare conveyance losses between different canals it is useful to convert the steady state loss to a loss rate. The convention for large canals is to express losses in terms of a unit wetted area of a canal:

$$S_L = \frac{Q_L}{WA} = \frac{Q_L}{(WP*L)} \qquad (4.15)$$

where:

S_L = the loss per unit wetted area (m/sec),

WA = wetted area of the canal, WP x L, (m^2)

WP = wetted perimeter length (m),

L = canal section length between the inflow and outflow measurement points (m).

S_L has units of volume per unit time per unit area, or length per unit time, and is thus equivalent to a seepage rate. It represents a depth of water infiltrated into the bed and banks of a canal in a unit of time.

In small channels, especially those which are used intermittently, the seepage rate varies considerably around the wetted perimeter. The seepage rates into the upper banks will be several times greater than the seepage rate into the bed. Thus losses are not proportional to the wetted perimeter and should therefore be expressed only per unit length as follows:

$$Q_{L/m}=\frac{Q_L}{L}=\frac{(Q_{inflow}-Q_{out})}{L} \tag{4.16}$$

where:

$Q_{L/m}$ = the average loss rate per unit length of canal (l/s/km).

Note: the preceding formulae and their definitions are taken from the comprehensive report "Diagnosing Problems With Irrigation Conveyance Channels" produced by the Water Management Synthesis Project at Colorado State University (Trout, 1982).

A number of tests were conducted at the four sites, mainly during water scarce periods when water deliveries were rotated from branch to branch. During this period when water would be conveyed through one canal at a time, various canal sections could be isolated where flow measurement structures were already in place to measure inflow and outflow. Tests were generally conducted over a period of a few hours. If a datalogger was in place on one of the structures, its records were used, otherwise one person would monitor and record the flow measurements at the inlet and another at the outlet. Measurements would typically be made every 10 to 15 minutes after the flow had stabilized in the section being tested.

Data from the various canal seepage tests is summarized in Appendix A.

4.3.6 Groundwater Level

The depth to the water table below the ground surface was measured at nine sites throughout the study areas (refer to Figure 3.1, back pocket). Existing wide diameter shallow wells were used to lower a weight on the end of a tape measure for measurement. Readings were taken every two weeks. Waterlogging, or the potential contribution to CWR (refer to Equation 4.6) could thus be noted.

4.4 Agricultural Production

4.4.1 Cropping Pattern and Intensity

Large spreadsheet files under separate cover contain the following information for each of the four study areas:

- farmer's name,
- canal outlet code number,
- gross land area,
- owner or tenant status,
- crops planted,
- crop varieties,
- planting and harvest dates,
- growth period for each crop,
- area planted to each crop,
- reported yield of each crop, and
- use of fertilizer.

From this data it was possible to determine the various cropping patterns (sequences), the total area planted to each crop, and the overall cropping intensity. The cropping intensity is expressed by a cropping intensity ratio (CIR) which reflects the summation of the percentage of cultivatable land which is actually under production in each crop season.

$$CIR=\frac{\sum_i (A_c)}{A_n} \tag{4.17}$$

where:

CIR = the annual cropping intensity ratio,

A_c = the total cropped areas for each crop season through the year (ha),

A_n = the net cultivable area

i = the number of crops grown in the crop year.

Generally, farmers reported accurately the area planted to each crop. Nevertheless, most farm plots were measured and the exact areas calculated to ensure accurate results.

Cropping intensity ratios for each of the four study areas are included Sections 5.3 and 5.5.

4.4.2 Crop Production

The yields of the two principal dry season crops, wheat (season 2) and maize (season 3), were determined by taking random samples from farmers' fields. The crop yields were determined by the following process:

- four to six random areas of one square metre were selected at the time of harvest (wheat), ten square meters for maize, - the crop was cut and placed in a bag,
- the number of stalks were counted to determine the plant population (wheat), the number of cobs for maize,
- the grain was dried, threshed by hand and weighed,
- the moisture content was measured with a moisture meter,
- the yield was thus calculated on a Tonne/ha basis at a standard 14% moisture content (MC) for reference purposes as follows:

$$Y=\frac{W_s}{A_s*1000*\left[\frac{(1-MC_s)}{(1-0.14)}\right]} \tag{4.18}$$

where:

Y = yield (T/ha), at 14% MC,

W_s = sample weight (grams),

A_s = sample area (m^2),

MC_s = sample moisture content (%).

The sample crop yields for wheat and maize are tabulated in Section 5.4. Farmers' reported yields are also included and the error (%) between reported and measured yields calculated.

Reported yields for all crops grown by all the farmers in the four study areas are also tabulated in Section 5.3.

4.5 Management and Maintenance Activities

During the course of 10 months spent living and working amongst the SMIS farmers, there was great opportunity to observe their activities. Irrigation management and system maintenance activities were recorded in notes and on video, through observation and active participation with farmers in their work.

Managment activities included:

- committee meetings, general meetings, and elections;
- direction of water allocation and deliveries - from the system to the field level,
- planning and execution of new works projects, and
- direction of maintenance activities.

Maintenance activities included:

- water diversion from the Tinau River,
- annual evacuation of sediment from the main and branch canals, and
- emergency repair works.

CHAPTER 5

RESULTS AND ANALYSIS

5.1 Water Use Efficiency

5.1.1 Definition

In general terms the expression irrigation efficiency or "water use efficiency" (WUE) has been defined as the ratio of water consumed by the crop ("productive" water) to the water diverted from a river or natural source into the irrigation system (the total volume of water supplied) (ASAE, 1983). Yoder (1986) further qualifies the water use efficiency term by stating that it is a meaningful criterion (or measure) of system performance only if water is a scarce and limiting resource. Therefore this thesis has concentrated on the examination of WUE during the winter and spring crop seasons when water is relatively scarce and when WUE is thus a more significant issue. Obviously if the supply of water is greater than required, but there is no possibility of intensifying the level of cropping or increasing the area under cultivation, then water use efficiency is not a fair means of judging performance.

The calculation of water use efficiency required measurement of the water supply available at the various levels in the physical system infrastructure (refer to Sections 4.3.2 - 4.3.4), the amount of water required and used by crops grown (CWR) (refer to Section 4.2), and the "loss" of water at the various levels within the system ("losses" being loosely defined as water not directly used in crop production, refer to Section 4.3.5).

The movement of water through the irrigation system, from the water source or intake to the crop, can be regarded as three separate operations: conveyance, distribution, and field application. Conveyance is the movement of water from its source through the main and lateral (or secondary) canals or conduits to the tertiary offtakes. Distribution is the movement of water through the tertiary (distributary) and farm canals or conduits to the field inlets. Field application is the movement of water from the field inlets to the crop. The efficiencies of water use in each of these operations are defined as follows. (Bos and Nugteren, 1978.)

The Conveyance efficiency (E_c) is the efficiency of the main canal network from the river diversion to the offtakes of the distributary system. It can be expressed as:

$$E_c = \frac{(V_d + V_2)}{(V_c + V_1)} \tag{5.1}$$

where:

V_c = volume diverted or pumped from the source (m^3),
V_d = volume delivered to the distribution system (m^3),
V_1 = inflow from other sources (m^3),
V_2 = non-irrigation deliveries from the conveyance system (m^3).

For the purposes of this thesis, E_c is confined to the main canal which conveys water from the two river intakes to the 30 inlets of the branch canal systems.

Distribution efficiency (E_d) is the efficiency of the water distribution canals and conduits supplying water from the conveyance network to individual fields. It can be expressed as:

$$E_d = \frac{V_f + V_3}{V_d} \tag{5.2}$$

where:

V_f = volume furnished to the fields (m^3),
V_3 = non-irrigation deliveries from the distribution system (m^3).

Here E_d is broken down into two parts, the distribution efficiency of (i) small branch systems (such as West

Siddhanagar) with canal capacities of less than 0.100 m^3/s and (ii) large branch systems (such as Anandavan Madhuban) with canal capacities of 0.100 - 0.500 m^3/s.

As both E_c and E_d are based on canal seepage losses (refer to Section 4.3.5), which are reported in flow rate per kilometre (l/s/km) terms rather than in simple percentage terms. This qualification is made to facilitate more accurate comparison of results, since efficiencies will obviously decrease in systems which must convey and distribute water over longer distances to fields. Furthermore, these losses are qualified in terms of the relative size of flows to which the efficiency ratings apply with respect to the maximum flow capacity of the particular canal system. Efficiencies are then calculated in ratio (percentage) terms for each particular case.

Water application efficiency (E_a) is the relation between the quantity of water furnished at the field inlet and the quantity of water needed to maintain the soil moisture at the level required by the crop. The field application efficiency can be expressed as:

$$E_a = \frac{V_m}{V_f} \tag{5.3}$$

where:

V_m = volume of water needed to maintain the soil moisture at the required level for the crop (m^3).

This is an indirect means of establishing field application efficiency, since the water used by evapotranspiration for a crop equals the amount of water needed to maintain the required soil moisture for the crop.

Therefore Equation 5.3 could be rewritten as:

$$E_a = \frac{CWR}{V_f} \tag{5.4}$$

where:

CWR = crop water requirements for the interval under study (m^3)

The volume of water applied to the fields is compared to CWR for individual irrigation periods for a selected sample of farms, and is further related to typical E_a values for basin irrigation under similar conditions. In this case then relative application efficiency E_{ra} is defined as:

$$E_{ra} = \frac{\left(\frac{CWR}{V_f}\right)}{E_{oa}} = \frac{E_a}{E_{oa}} \tag{5.5}$$

where:

CWR = crop water requirements,
E_{oa} = the optimal application efficiency which can be reasonably expected for such a system (from literature).

The evaluation of the field application efficiency requires:

i) the measurement of water delivery to each field,

ii) measurements of soil moisture content before each application of irrigation water,

iii) the evapotranspiration rates of the various crops cultivated (ET_{crop}) and the variation in them during the growing season,

iv) the moisture retention of the soils between field capacity and a preselected depletion limit (the lowest acceptable moisture content that does not significantly affect yields), and,

v) the infiltration rate of the relevant soils (Bos and Nugteren, 1978).

Irrigation system efficiency (E_s) is the combined efficiency of the water conveyance and distribution systems; and if non-irrigation deliveries are insignificant compared with the volume of water delivered to the fields, irrigation system efficiency may be expressed as:

$$E_s = E_c * E_d \qquad (5.6)$$

Irrigation system efficiency is expressed here for the specific branch systems during the particular time periods for which it was evaluated.

Finally, the data used to assess the separate efficiencies can also be used to assess a project's overall irrigation efficiency.

If the values of V_1, V_2, and V_3 are negligible compared with V_c and V_m, as is typically the case, then the overall or project efficiency (E_p) can be expressed as:

$$E_p = E_c * E_d * E_a \tag{5.7}$$

5.1.2 Data Used

i) Canal seepage test results are summarized in Table 5.1.

ii) A summary of efficiencies as reported in literature is included in Table 5.2.

ii) Flow measurement data is summarized in Appendix A.

Table 5.1 Summary of SMIS canal conveyance and distribution loss tests

CANAL	CANAL TYPE (Class) Capacity* (m^3/s)	AVERAGE INFLOW[1] (m^3/s)	LENGTH OF TEST SECTION (km)	CONVEYANCE/ DISTRIBUTION LOSSES[2] ($m^3/s/km$)	(%/km)
SMIS Main	Large Main (Conveyance) 10.0 - 30.0*	0.320 (v.low)	2.80	0.064	20
				(Av=0.067)	
		0.285 (v.low)		0.070	26
A-M Main (Br. 2) & (Br. 4)	Medium (Distributary) 0.3 - 0.6*	0.140 (moderate)	2.90	0.013	9
		0.180 (moderate)	2.0	0.018	10
		0.100 (moderate)	2.0	0.016	16
				(Av=0.016)	
West Siddhanagar	Small (Distributary) 0.050*	0.003 (low)	0.80	0.0006	19
		0.020 (moderate)		0.0035	23
		0.065[3] (very high)		0.0300	46

Notes:

[1] Average flow over the duration of the test period.

[2] Assumed constant rates over the test section.

[3] Flows in excess of canal capacity, therefore some overtopping, and leakage over and around structures occurring.

Table 5.2 Review of efficiencies as reported in literature

SOURCE	E_c(%)	E_d(%)	E_s(%)	E_a(%)
Water distribution at Gumain River Irrigation System[1]	-	85	-	45
BLGWP[2]	-	85	-	70
ICID Surveys[3]	50-90	60-90	30-80	60
North India[4]	83	20-92	55	-
Reddi[5]	80	80	-	40-80
FAO[6]	-	-	-	45-75
ASAE[7]	-	-	-	70-90

Notes:

1 Weller and Green, 1989
2 Tahal, 1988
3 Bos and Nugteren, 1974
4 Misra and Ahmed, 1987
5 Reddi, 1976
6 FAO, 1977
7 ASAE, 1983

5.1.3 Analysis

Before presenting the analysis of the seepage loss test data it is important to note the following points throughout this section:

- loss rates will vary in this research as tests were made at different flow rates, and on different canals,
- loss rates are proportional to the wetted area of the canal and are typically stated in terms of a unit wetted area (Trout, 1982),
- in these tests, inflow rates varied over the duration of most tests, and the wetted perimeters of the canals tested varied considerably due to the non-uniformity of the canal cross-sections, therefore losses could not be reported in terms of a unit wetted area,
- loss rates may vary between being constant and proportional to the flow rate, but unless the evidence for variable rates is clear, they should be assumed constant in order to simplify calculations (Trout, 1982),
- the tests were carried out during the dry season when canal inflows are their lowest and losses their highest of the year, consequently the results evaluated here must be considered as the worst case scenario and are not indicative of water delivery performance throughout the entire year.

5.1.3.1 Conveyance Efficiency

The SMIS main is an unlined earthen canal. Conveyance efficiency of the SMIS main canal was evaluated by analyzing seepage losses over a 2.8 km section during the dry season (between Taraprasad bhod and the A-M main inlet weir). The results of the seepage loss tests on which this evaluation is based are summarized in Table 5.1. Conveyance efficiency is very poor during periods of water scarcity in the spring when inflows are very low (relative to canal capacity). Conveyance losses under these conditions are in the order of 20-26 percent per kilometre (%/km) or 0.064-0.070 $m^3/s/km$, with loss assumed to be at a constant rate.

Given an average constant main canal seepage loss of 0.067 $m^3/s/km$, overall conveyance efficiency will vary considerably for individual branch canal areas which abstract water along the length of the main canal (It should be noted that local variations in canal cross-section, underlying soil type, etc., may result in some local variations in the seepage loss rate). Moving from the head to the tail end of the main canal during periods of low inflow, conveyance efficiencies will steadily worsen (refer to Table 5.3). In fact, when very low inflows were observed in early May (Q_{in} = 0.150-0.200 m^3/s), water deliveries could not be made further than four to five

Table 5.3 Typical conveyance and distribution efficiency ratings crop season 3, April/May, 1989.

Canal	Range of Delivery Distance (km)	Average Distance (km)	Loss Rate ($m^3/s/km$)	Typical Inflow (m^3/s)	Efficiency[2] (%)
SMIS main	0.3-5.0[1]	2.12	0.067	0.300	53 (E_c)
Anandavan Madhuban	2.0-4.0	2.7	0.016	0.140	69 (E_d)
West Siddha-nagar	0.3-0.9	0.6	0.0035	0.020	87 (E_d)

[1] Farthest south delivery point in SMIS main during April/May was A-M "lower" at 5.0 km from Taraprasad bhod.

[2]

$$Efficiency = \frac{(Average\ Distance) * (Loss\ Rate)}{(Typical\ Inflow)}$$

kilometres downstream from Taraprasad bhod as the entire flow was lost to seepage.

An average value for conveyance efficiency under spring dry season conditions (based on losses over the average delivery length of 2.12 km to the branch canals receiving water) would be 53%. Obviously the wide variation in main canal conveyance efficiencies (0-89%) applied to individual branch canal areas distributing water off the main canal at this time of year, has considerable influence on the measures of water allocation/equity and water adequacy (refer to Sections 5.2 and 5.3).

In general, conveyance losses may be attributed to five components:

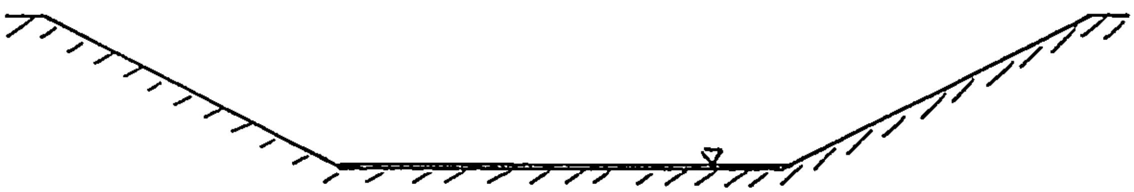
i) evaporation from the water surface,
ii) re-wetting of the canal bed and banks which have dried out since the last irrigation,
iii) leakage through or over the canal banks onto the surrounding fields,
iv) seepage and deep percolation,
v) leakage through control structures or unregulated openings to other canals or to fields.

In the case of the SMIS main, observations indicate that seepage (iv), leakage (v) and perhaps some re-wetting (ii) are the principal components of water loss (in order of their significance). Unlined earthen canals typically have poor conveyance efficiencies ranging from 50-70% for similar systems (Bos and Nugteren, 1978). Unfortunately, literature does not indicate typical seepage loss rates and subsequently E_c for unlined canals in terms of their length or indicate whether losses are constant or proportional to flow which would facilitate a more meaningful comparison and analysis of results.

It could be postulated that the SMIS main canal conveyance efficiency would be much higher when it is carrying much higher flows which are closer to its capacity. Since seepage loss is proportional to the wetted perimeter, Figure 5.1 indicates clearly that for a very large increase in flow (from the very low dry season to the monsoon for instance) a much smaller proportional increase in wetted perimeter results. This is due to the fact that the SMIS main canal is designed to carry high monsoon flows for continuous delivery of water for rice cultivation. Therefore the canal bottom is very wide and the canal is inefficient at conveying low flows.

This hypothesis was tested by determining the seepage loss rate which corresponded to a much higher flow, and then comparing the effective conveyance efficiency (E_c) at various points along the canal at a low and a high flow. The seepage

(a) Flow, Q = 0.300 m^3/s (dry season)
Wetted Perimeter = 3.130 m
Seepage Loss = 0.067 $m^3/s/km$ (measured)
Average Conveyance Efficiency = 24%



(b) Flow, Q = 9.535 m^3/s (monsoon season)
Wetted Perimeter = 5.236 m
Seepage Loss = 0.110 $m^3/s/km$ (derived)
Average Conveyance Efficiency = 96%

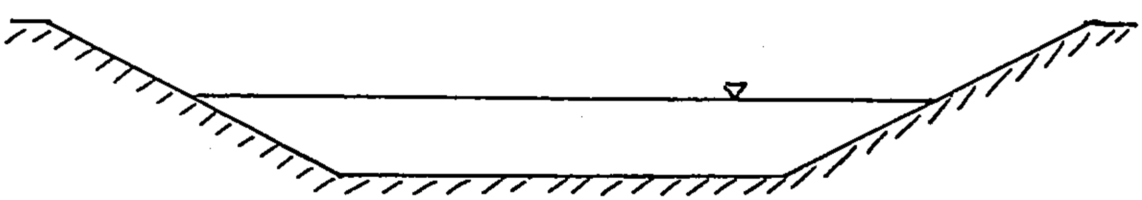


Figure 5.1 Influence of the variation of flow in the SMIS main canal on the wetted perimeter.

loss rate was assumed to be proportional to the wetted perimeter of the canal. The proportional relationship was determined based on the seepage tests (at a relatively low flow) and extrapolated to derive seepage losses corresponding to higher flows (refer to Table 5.4). Theory indicates that as the wetted perimeter extends up the canal banks for higher flows in a canal, the increase in seepage loss proportionate to the wetted perimeter will decline. This is due to the lower head available to move water out of the canal and into the banks, whereas the maximum head available will produce a proportionately higher rate of seepage loss through the canal bed. Therefore, the assumed directly proportional relationship between the seepage loss rate and the wetted perimeter in Table 5.4 is conservative, and is employed here only for hypothetical analysis.

Figure 5.1 illustrates the wetted perimeter for (a) a flow of 0.300 m^3/s during the (dry season) seepage tests and for (b) a flow of 9.5 m^3/s which would be typical of monsoon season flow conditions. Table 5.5(a) lists the E_c values for various points along the canal during dry season (low) flow conditions. Table 5.5(b) lists the E_c values for various points along the canal during the monsoon (high) flow conditions. This analysis clearly shows that for a 32 fold increase in flow, seepage loss will only increase 1.64 times.

Table 5.4 Derivation of seepage loss rates for varied flows in the SMIS main canal

DEPTH OF FLOW (m)	HYDRAULIC RADIUS (m)	AREA OF FLOW (m^2)	VELOCITY (m/s)	FLOW (m^3/s)	SEEPAGE LOSS RECORDED (m^3/s/km)	SEEPAGE LOSS DERIVED (m^3/s/km)
0.010	3.045	0.030	3.322	0.100		0.064
0.029	3.130	0.089	3.383	0.300	0.067	0.066
0.050	3.224	0.155	3.450	0.535		0.068
0.100	3.447	0.320	3.608	1.155		0.072
0.200	3.894	0.680	3.914	2.661		0.082
0.300	4.342	1.080	4.208	4.545		0.091
0.400	4.789	1.520	4.492	6.828		0.101
0.500	5.236	2.000	4.768	9.535		0.110
0.600	5.683	2.520	5.035	12.689		0.119
0.700	6.130	3.080	5.296	16.312		0.129
0.800	6.578	3.680	5.551	20.427		0.138
0.900	7.025	4.320	5.800	25.054		0.148
1.000	7.472	5.000	6.043	30.216		0.157

Notes:

CANAL: SIDE-SLOPES = 1:2
BOTTOM - WIDTH = 3.0 m
MANNING "n" = 0.040
SLOPE = 0.004 m/m

Table 5.5(a) Conveyance Efficiencies (E_c) Relative to Level of Main Canal Flow

With Q_{in} = 0.300 m^3/s, and Q_{loss} = 0.067 $m^3/s/km$ (measured average):[1]

Delivery to Branch Area Outlet From Main Canal	Distance[2] (km)	Main Canal Seepage Loss		Eff E_c
		(m^3/s)	(%)[3]	
West Siddhanagar	0.5	0.034	7	0.89
Anandavan Madhuban	2.8	0.188	38	0.37
Average Efficiency based on the mid-point of the Main canal	3.4	0.228	46	0.24
Khopiya	6.8	0.456	91	0[4]

Notes:

1 Typical of dry season conditions (late March through early May).

2 Distance from Taraprasad bhod to the branch area.

3 percentage of Q_{in} lost over the delivery distance

4 Given the above conditions, the entire flow is lost to seepage in 4.5 km.

Table 5.5(b) Conveyance Efficiencies (E_c) Relative to Level of Main Canal Flow

If Q_{in} = 9.500 m^3/s, and Q_{loss} = 0.110 $m^3/s/km$ (derived):[1]

Delivery to Branch Area Outlet From Main Canal	Distance[2] (km)	Main Canal Seepage Loss		Eff E_c
		(m^3/s)	(%)[3]	
West Siddhanagar	0.5	0.055	1	0.99
Anandavan Madhuban	2.8	0.308	3	0.97
Average Efficiency based on the mid-point of the Main canal	3.4	0.374	4	0.96
Khopiya	5.8	0.748	8	0.92

Notes:

1 Typical of monsoon conditions (June through September).

2 Distance from Taraprasad bhod to the branch area.

3 Percentage of Q_{in} lost over the delivery distance.

Consequently the average E_c for the mid-point of the canal jumps from 0.24 in the dry season to 0.96 in the wet season.

Although this analysis is based on some standard assumptions and may be subject to some limited errors, it is clear that in principle the conveyance efficiency of the main canal is very poor and a problem only during the drier months of the year when flows are much lower than during the monsoon. This is directly related to canal cross-section design principles, which endeavour to utilize the least wetted perimeter for the greatest flow capacity in order to minimize seepage losses (as well as the reduce friction loss, maximize flow per cross-sectional area, and maximize economic efficiency).This factor is clearly in evidence here - the canal is designed to carry very high flows (10.0 - 30.0 m^3/s) and performs very efficiently in those conditions. However, the canal performs very inefficiently for low flows and a more efficient cross-section (ie. that one is narrower and produces deeper, faster flow) would be effective in increasing the dry season E_c.

5.1.3.2 Distribution Efficiencies

Seepage losses, while still significant, are much less in the distributary canals of the individual branch canal systems than in the SMIS main canal. Average distribution efficiencies (E_d) for the three branch systems (maujas) studied are listed in Table 5.6. The seepage loss tests of the branch canals were also carried out during the dry season, but flows in the branches were still in the range of the respective canal capacities as water was rotated from the main canal to one or several branch canals at a time. For example, the total main canal flow of 0.300 m^3/s might have been all diverted to the Anandavan Madhuban branch, utilizing the branch canal to near its full capacity. Therefore, a much more efficient wetted perimeter to flow relationship resulted for the branch canals than for the main canal during the dry season. It should also be noted that because the E_d values from these tests were determined for the canals at near capacity conditions, they should hold with minimal variation throughout the year.

Distribution efficiencies of approximately 70% are found in the large Anandavan Madhuban branch system where water must be conveyed over distances of two to five kilometres from the main canal inlet before reaching the farms. Distribution efficiency is highest (approximately 90%) in the smaller West Siddhanagar branch system where the distance from the main canal to the farms is much less. The range of E_d of 70-90% for the SMIS is therefore typical of the delivery performance of other earthen channel distribution systems (refer to Table 5.2). E_d has been maximized during the dry season by the careful management of the rotation system by SMIS farmers. Nevertheless there is room for improvement in the E_d.

Table 5.6 Distribution efficiencies for branch canals

Branch Area	Average Delivery Distance[1] (km)	Seepage Loss Rate (l/s/km)	Typical Inflow[4] (m^3/s)	E_d
West Siddhanagar	0.6	0.0035[2]	0.020	0.89
Anandavan Madhuban	2.7	0.016[2]	0.140	0.69
Khopiya	0.9	0.010[3]	0.050	0.82

Notes:

1 Average delivery distance from the branch canal inlet on the main canal to the farmer's field or field ditches within that area.

2 From Table 5.1

3 Estimated based on Table 5.1, canal cross-section and construction, and soil conditions.

4 From irrigation flow monitoring records.

It is interesting to note however that when flows higher than canal capacity were distributed in West Siddhanagar, a reduced distribution efficiency of 72% resulted, (losses = [(0.6 km x 0.03 m^3/s/km) / (0.065 m^3/s)] - refer to Table 5.1). From observation at the time of testing it was clear that overtopping losses and losses around farm ditch inlets were very high due to the overloading of the canal.

5.1.3.3 Irrigation System Efficiency

Accurate evaluation of the irrigation system efficiency requires examination of branch canal systems individually. The conveyance efficiency of the main canal to the branch canal inlet is factored together with the distribution efficiency from the branch inlet to the farm level. Irrigation system efficiencies are tabulated in Table 5.7(a) and (b).

As E_s simply reflects E_c and E_d the same spatial variation of decreasing system efficiency from head to tail of the irrigation system should be noted. Conveyance, distribution, and consequently system efficiencies can be improved by improvements to the physical water distribution infrastructure as discussed in Section 7.1.

Table 5.7 Irrigation system efficiencies for the individual branch canal areas

(a) Dry Season (March - May)

Branch Canal	$E_s = (E_c^1 * E_d^2)$
West Siddhanagar	0.79 = 0.89 * 0.89
Anandavan Madhuban	0.26 = 0.37 * 0.69
Khopiya	0 = 0 * 0.82

(b) Monsoon (June - September)

Branch Canal	$E_s = (E_c^1 * E_d^2)$
West Siddhanagar	0.88 = 0.99 * 0.89
Anandavan Madhuban	0.67 = 0.97 * 0.69
Khopiya	0.75 = 0.92 * 0.82

Notes:

[1] E_c values from Table 5.5(a) and (b)

[2] E_d values from Table 5.6

5.1.3.4 Application Efficiency

Definitive, quantitative analysis of the application efficiency for individual farms was beyond the scope of this research. Such analysis would require collection of a considerable amount of additional data such as soil moisture tracking (refer to Section 5.1.3.1). The decision was made at the beginning of this research to concentrate on evaluating he performance of the entire system. Consequently water measurements at all levels were deemed to be the more significant in terms of an overall understanding of how the system operated than were extensive measurements at the field (micro) level. It was beyond the logistical (workload) capacity of this project to undertake such measurements. Nevertheless some observations and qualitative assessment of SMIS farmers' water application practices are made below in order to provide as complete an understanding of the system as possible.

Basin irrigation as practised in the SMIS has a high potential application efficiency of about 85% (ASAE, 1983). The only potentially significant water losses could be deep percolation or spillage. The small areas of individual basins and the care with which land is levelled in the SMIS typically allow water to uniformly cover a basin in 30 to 60 minutes, a fraction of the overall infiltration time. Therefore it is likely that application efficiencies are high for most farmers who irrigate directly to basins from farm ditches. Some farmers however irrigate from basin to basin which must result in lower efficiencies due to much higher overall percolation losses.

The assessment of crop water requirements versus irrigation deliveries (described in Section 5.3) provides some indication of the SMIS farmers' irrigation practices. Significant points to consider include the following:

- farmers tended to apply more water frequently when the supply was adequate and available on demand;
- most farmers irrigated in a timely manner, corresponding to the most critical growth stages of their crops, provided water was available;
- the majority of farmers applied more water than the gross CWR, however, it is not clear what portion of that excess water could be contributed to unavoidable field losses versus what might be considered to be over-application;
- when the water supply was limited and available only on a three to four week rotation basis (during crop season 3), some farmers apparently over-irrigated in an effort to take as much water as possible during the time that it was available to them.

5.2 Water Allocation and Equity

5.2.1 Definition

The water supply measurements at the various levels throughout an irrigation system may be utilized to evaluate another measure of performance - the allocation of irrigation water and the equity of its distribution. The SMIS abides by water allocation principles - which entitle each farmer to receive a certain proportion of water delivery (refer to Section 3.2.5.1). The degree to which a farmer's allotment of water is filled over a particular crop season is a key measure of the irrigation system's performance.

A high level of sensitivity to water allocation on the part of farmers is embodied in the concept of equity (or fairness) in the allocation of water. Equity is generally accepted as an objective of the operation of an irrigation system. As a measure of performance however, equity is difficult to evaluate because of complex interactions between soils, slopes of the land, crops, etc. and their variation between sites. Therefore equity cannot be simply viewed as equal water distribution on the basis of land. For example, variation in soil type within a system may result in considerable differences in unavoidable seepage and percolation (S&P)

losses; therefore for equitable water allocation to occur, larger supplies of water should be provided to areas where S&P rates are higher. SMIS farmers have derived and established what they perceive to be as an equitable water allocation principle over a period of many years which indicates that spatial variation in the water requirements of different areas within the system have been accounted for (refer to Section 3.2.5.1).

5.2.2 Data Used

i) The water allocation principles for the SMIS are detailed in Section 3.2.5.1.

ii) Flow monitoring data (water deliveries to the branch canal study areas and the water supply available at the head) is summarized in Appendix A.

iii) Water rotation schedules and deliveries during the two rotation periods in the spring of 1989 are under separate cover.

iv) Tables 5.8 and 5.9 compare monthly (or rotation period) water allocation against actual deliveries of water.

v) Tables 5.10 and 5.11 tabulate how closely the SMIS management came to meeting the water allocation principle during the two water rotation periods both in terms of time of delivery and volume of water delivery.

Table 5.8 Water allocation versus availability and delivery to branch systems

MONTH/ PERIOD	BRANCH	WATER AVAILABLE AT HEADWORKS MONTH/PERIOD (ha-m)	ALLOCATION (ha-m)	ACTUAL DELIVERY AT INLET (ha-m)	AT HEAD (ha-m)	DIFFERENCE (%)	LOSSES (%)
JAN.	W-SID	165.250	2.637	2.564	2.637	-2.767	
	A-M		26.370	18.243	26.370	-30.818	
	KHOPIYA		1.758	0.000	1.758	-100.000	
FEB.	W-SID	123.816	1.976	3.217	1.976	62.821	
	A-M		19.758	20.236	19.758	2.420	
	KHOPIYA		1.317	0.359	1.317	-72.745	
MAR.	W-SID	63.429	1.012	0.664	1.012	-34.398	
	A-M		10.122	1.177	10.122	-88.371	
	KHOPIYA		0.675	0.148	0.675	-78.067	
ROT #1	W-SID	73.944	1.328	0.997	1.097	-24.944	-9.089
	A-M		17.095	8.475	19.251	-50.425	-55.977
ROT #2	W-SID	80.939	1.454	0.323	2.379	-77.785	-86.424
	A-M		19.574	5.157	16.421	-73.654	-68.596

Notes:

ALLOCATION = ALLOCATION (ENTITLEMENT) OF WATER BASED ON PROPORTION OF TOTAL WATER SUPPLY AVAILABLE OVER THE MONTH OR ROTATION PERIOD.

DIFFERENCE = THE DIFFERENCE BETWEEN THE ENTITLED PROPORTION AVAILABLE AT THE HEAD (TARAPRASAD BHOD) AND THE ACTUAL VOLUME DELIVERED TO THE BRANCH INLET

LOSSES = THE PROPORTION OF THE ACTUAL WATER SUPPLY AVAILABLE AT THE HEAD WHICH IS LOST BY SEEPAGE, LEAKAGE, WATER THEFT, ETC. BEFORE REACHING THE DELIVERY POINT AT THE INLET OF THE BRANCH CANAL

Table 5.9(a) Assessment of water allocation based on the time of delivery to branch systems during rotation period #1

ROTATION #1:

MAUJA	KULARA	ALLOCATION TIME (hrs)	ACTUAL TIME (hrs)	START	FINISH	PERCENT OF ALLOCATION TIME	PERCENT OF ACTUAL TIME	PERCENT GAIN OR LOSS
TAIL AREA	29	174	144	26-Mar 06:00	01-Apr 06:00	31.9	23.9	-25.2
A-M (LOWER #10 & JODENI)	3	18	23	01-Apr 06:00	02-Apr 05:00	3.3	3.8	15.5
25 BIGHA DINGERNAGAR	1	6	7	02-Apr 05:00	02-Apr 12:00	1.1	1.2	5.4
BISHNUPUR	6	40	42	02-Apr 12:00	04-Apr 06:00	7.3	7.0	-5.1
BHAKTAPUR	4	26	29	04-Apr 06:00	05-Apr 11:00	4.8	4.8	0.8
ANANDAVAN MADHUBAN	15	126	164.5	05-Apr 11:00	12-Apr 07:30	23.1	27.3	18.0
LOWER & OLD JANAKINAGA	8	50	58.5	12-Apr 07:30	14-Apr 18:00	9.2	9.7	5.7
NEW JANAKINAGAR	3	18	24	14-Apr 18:00	15-Apr 18:00	3.3	4.0	20.5
UPPER DINGERNAGAR	2	12	15	15-Apr 18:00	16-Apr 09:00	2.2	2.5	13.0
DINGERNAGAR & E. SIDD.	7	42	52	16-Apr 09:00	18-Apr 13:00	7.7	8.6	11.9
W. SIDD.+LOWER/37B. DEV.	5.5	33	44	18-Apr 13:00	20-Apr 09:00	6.1	7.3	20.5
TOTALS:	83.5	545	603			100.0	100.0	

Notes:

MARCH 26 – APRIL 20, 1989
CHAITRA 13, 2045 – BAISAHK 08, 2046

- NORMAL ALLOCATION = 6 HOURS WATER DELIVERY / KULARA
- EXTRA TIME GIVEN SOME MAUJAS FOR WATERING CATTLE

TAIL AREA MAUJAS:

SURAYAPURA	DEVINAGAR
SUPAULI	EAST PAUNI
KHAIRIYA	WEST PAUNI
SEMERI	SALGHARI-BHALDODARI
NANDANAGAR	HERPUR – GORKATTA
NERSINGHGADH	GANESHPUR
BAGDHURAWA	

% GAIN OR LOSS – THE DIFFERENCE BETWEEN THE ACTUAL PROPORTION OF TIME DURING WHICH WATER WAS DELIVERED AND THE ENTITLED PROPORTION OF TIME [(% ACTUAL – % ALLOCATED) / %ALLOCATED]

Table 5.9(b) Assessment of water allocation based on the time of delivery to branch systems during rotation period #2

ROTATION #2:

MAUJA	KULARA	ALLOCATION TIME (hrs)	ACTUAL TIME (hrs)	START	FINISH	PERCENT OF ALLOCATION TIME	PERCENT OF ACTUAL TIME	PERCENT GAIN OR LOSS
TAIL AREA	29	174	168	22-Apr 12:00	29-Apr 12:00	33.4	21.0	-37.2
A-M LOWER #10	2	12	72	29-Apr 12:00	02-May 12:00	2.3	9.0	290.3
A-M JODENI	1	6	30	02-May 12:00	03-May 18:00	1.2	3.7	225.2
25 BIGHA DINGERNAGAR	1	6	41	03-May 18:00	05-May 11:00	1.2	5.1	344.5
BISHNUPUR	6	40	70	05-May 11:00	08-May 09:00	7.7	8.7	13.8
ANANDAVAN MADHUBAN	15	126	165	08-May 09:00	15-May 06:00	24.2	20.6	-14.8
BHAKTAPUR	4	26	36	15-May 06:00	16-May 18:00	5.0	4.5	-9.9
LOWER JANAKINAGAR	2	12	14	16-May 18:00	17-May 08:00	2.3	1.7	-24.1
OLD JANAKINAGAR	6	38	60	17-May 17:00	20-May 05:00	7.3	7.5	2.7
NEW JANAKINAGAR	3	18	31	20-May 05:00	21-May 12:00	3.5	3.9	12.0
DINGERNAGAR	6	36	60	21-May 12:00	24-May 00:00	6.9	7.5	8.4
UPPER DINGERNAGAR	2	12	20	24-May 00:00	24-May 20:00	2.3	2.5	8.4
WEST SIDDHANAGAR	1.5	9	15	24-May 20:00	25-May 11:00	1.7	1.9	8.4
EAST SIDDHANAGAR	1	6	19	25-May 11:00	26-May 06:00	1.2	2.4	106.0
TOTALS:	79.5	521	801			100.0	100.0	

Notes:

APRIL 20 - MAY 26, 1989

- NORMAL ALLOCATION = 6 HOURS WATER DELIVERY / KULARA
- EXTRA TIME GIVEN SOME MAUJAS FOR WATERING CATTLE
- ROTATION NOT FINISHED AS RAIN AND HIGHER CANAL FLOWS CAME... SO WATER WAS SUPPLIED ON DEMAND TO ALL BRANCHES

TAIL AREA MAUJAS:

SURAYAPURA	DEVINAGAR
SUPAULI	EAST PAUNI
KHAIRIYA	WEST PAUNI
SEMERI	SALGHARI-BHALDODARI
NANDANAGAR	HERPUR - GORKATTA
NERSINGHGADH	GANESHPUR
BAGDHURAWA	

% GAIN OR LOSS = THE DIFFERENCE BETWEEN THE PROPORTION OF ACTUAL TIME DURING WHICH WATER WAS DELIVERED AND THE ENTITLED PROPORTION OF DELIVERY TIME BASED ON THE ALLOCATION PRINCIPLE
[(% ACTUAL - % ALLOCATED) / % ALLOCATED]

Table 5.10(a) Assessment of water allocation based on the volume of water delivered to branch systems during rotation period #1

ROTATION #1:

MAUJA	KULARA	ALLOCATION TIME (hrs)	ACTUAL TIME (hrs)	AVERAGE FLOW (cms)	VOLUME DELIVERED (ha-m)	DELIVERY/ KULARA (ha-m)	PERCENT OF ALLOCATION TIME	PERCENT OF DELIVERY	PERCENT GAIN OR LOSS
TAIL AREA	29	174	144	0.424	21.986	0.758	31.9	29.7	-7.0
A-M (LOWER #10 & JODENI	3	18	23	0.400	3.310	1.103	3.3	4.5	35.4
25 BIGHA DINGERNAGAR	1	6	7	0.369	0.930	0.930	1.1	1.3	14.1
BISHNUPUR	6	40	42	0.361	5.454	0.909	7.3	7.4	0.4
BHAKTAPUR	4	26	29	0.333	3.479	0.870	4.8	4.7	-1.5
ANANDAVAN MADHUBAN	15	126	164.5	0.322	19.048	1.270	23.1	25.7	11.3
LOWER & OLD JANAKINAG	8	50	58.5	0.329	6.922	0.865	9.2	9.3	1.9
NEW JANAKINAGAR	3	18	24	0.334	2.889	0.963	3.3	3.9	18.1
UPPER DINGERNAGAR	2	12	15	0.320	1.728	0.864	2.2	2.3	6.0
DINGERNAGAR & E. SIDD.	7	42	52	0.248	4.635	0.662	7.7	6.3	-18.8
W. SIDD.+LOWER/37B. DEV	5.5	33	44	0.231	3.656	0.665	6.1	4.9	-18.6
TOTALS:	83.5	545	603	0.341	74.037	0.887	100	100.0	

Notes:

MARCH 26 – APRIL 20, 1989
CHAITRA 13, 2045 – BAISAHK 08, 2046

- NORMAL ALLOCATION = 6 HOURS WATER DELIVERY / KULARA
- EXTRA TIME GIVEN SOME MAUJAS FOR WATERING CATTLE
- KULARA = NUMBER OF KULARA

TAIL AREA MAUJAS:

SURAYAPURA	DEVINAGAR
SUPAULI	EAST PAUNI
KHAIRIYA	WEST PAUNI
SEMERI	SALGHARI-BHALDODARI
NANDANAGAR	HERPUR – GORKATTA
NERSINGHGADH	GANESHPUR
BAGDHURAWA	

% GAIN OR LOSS – THE DIFFERENCE BETWEEN THE ACTUAL PROPORTION OF THE AVAILABLE WATER SUPPLY WHICH WAS DELIVERED AT THE HEAD (NOT AT THE BRANCH CANAL INLETS) AND THE ENTITLED PROPORTION OF WATER WHICH SHOULD HAVE BEEN DELIVERED BASED ON THE TIME ALLOCATION PRINCIPLE [(% DELIVERY – % ALLOCATION) / % ALLOCATION]

Table 5.10(b) Assessment of water allocation based on the volume of water delivered to branch systems during rotation period #2

ROTATION #2:

MAUJA	KULARA	ALLOCATION TIME (hrs)	ACTUAL TIME (hrs)	AVERAGE FLOW (cms)	VOLUME DELIVERED (ha-m)	DELIVERY/ KULARA (ha-m)	PERCENT OF ALLOCATION TIME	PERCENT OF DELIVERY	PERCENT GAIN OR LOSS
TAIL AREA	29	174	168	0.204	12.336	0.425	33.4	15.3	-117.9
A-M LOWER #10	2	12	72	0.213	5.527	2.764	2.3	6.9	66.5
A-M JODENI	1	6	30	0.237	2.556	2.556	1.2	3.2	63.7
25 BIGHA DINGERNAGAR	1	6	41	0.225	3.315	3.315	1.2	4.1	72.0
BISHNUPUR	6	40	70	0.180	4.530	0.755	7.7	5.6	-38.4
ANANDAVAN MADHUBAN	15	126	165	0.243	14.453	0.964	24.2	18.0	-34.7
BHAKTAPUR	4	26	36	0.412	5.336	1.334	5.0	6.6	24.7
LOWER JANAKINAGAR	2	12	14	0.367	1.848	0.924	2.3	2.3	-0.3
OLD JANAKINAGAR	6	38	60	0.215	4.648	0.775	7.3	5.8	-26.3
NEW JANAKINAGAR	3	18	31	0.185	2.064	0.688	3.5	2.6	-34.7
DINGERNAGAR	6	36	60	0.723	15.613	2.602	6.9	19.4	64.4
UPPER DINGERNAGAR	2	12	20	0.426	3.067	1.533	2.3	3.8	39.5
WEST SIDDHANAGAR	1.5	9	15	0.413	2.231	1.487	1.7	2.8	37.7
EAST SIDDHANAGAR	1	6	19	0.440	3.013	3.013	1.2	3.7	69.2
TOTALS:	79.5	521	801	0.279	80.5	1.013	100.0	100.0	

Notes:

APRIL 20 – MAY 26, 1989

- NORMAL ALLOCATION = 6 HOURS WATER DELIVERY / KULARA
- EXTRA TIME GIVEN SOME MAUJAS FOR WATERING CATTLE
- KULARA = NUMBER OF KULARA
- ROTATION NOT FINISHED AS RAIN AND HIGHER CANAL FLOWS CAME... SO WATER WAS SUPPLIED ON DEMAND TO ALL BRANCHES

TAIL AREA MAUJAS:

SURAYAPURA	DEVINAGAR
SUPAULI	EAST PAUNI
KHAIRIYA	WEST PAUNI
SEMERI	SALGHARI-BHALDODARI
NANDANAGAR	HERPUR – GORKATTA
NERSINGHGADH	GANESHPUR
BAGDHURAWA	

% GAIN OR LOSS = THE DIFFERENCE BETWEEN THE ACTUAL PROPORTION OF THE AVAILABLE WATER SUPPLY WHICH WAS DELIVERED AT THE HEAD (NOT AT THE BRANCH CANAL INLETS) AND THE ENTITLED PROPORTION OF WATER WHICH SHOULD HAVE BEEN DELIVERED BASED ON THE TIME ALLOCATION PRINCIPLE [(% DELIVERY – % ALLOCATION) / % ALLOCATION]

Table 5.11 Water allocation versus availability and delivery to Anandavan Madhuban sub-branches

MONTH/ PERIOD	BRANCH	WATER AVAILABLE AT HEADWORKS MONTH/PERIOD (ha-m)	ALLOCATION (ha-m)	ACTUAL DELIVERY AT INLET (ha-m)	ACTUAL DELIVERY AT HEAD (ha-m)	DIFFERENCE (%)
JAN.	# 10	18.243	2.335	2.406	2.335	3.036
	7 BIGHA		0.328	0	0.328	-100.000
	# 12		2.992	2.213	2.992	-26.032
FEB.	# 10	20.236	2.590	1.782	2.590	-31.202
	7 BIGHA		0.364	0.448	0.364	22.993
	# 12		3.319	1.549	3.319	-53.325
MAR.	# 10	1.177	0.151	0.230	0.151	52.666
	7 BIGHA		0.021	0.000	0.021	-100.000
	# 12		0.193	0.022	0.193	-88.603
APRIL	# 10	8.525	1.091	0.733	1.091	-32.826
	7 BIGHA		0.153	0.218	0.153	42.066
	# 12		1.398	1.223	1.398	-12.524
MAY	# 10	5.157	0.660	0.163	0.660	-75.307
	7 BIGHA	**	0.093	0.102	0.093	9.883
	# 12	*	0.846	1.232	0.846	45.670
ROT #1	# 10		1.085	0.733	1.085	-32.430
	7 BIGHA		0.153	0.218	0.153	42.904
	# 12		1.390	1.223	1.390	-12.008
ROT #2	# 10		0.660	0.163	0.660	-75.307
	7 BIGHA		0.093	0.102	0.093	9.883
	# 12		0.846	0.322	0.846	-61.939

Notes:

ALLOCATION = ALLOCATION (ENTITLEMENT) OF WATER BASED ON PROPORTION OF TOTAL WATER SUPPLY AVAILABLE OVER THE MONTH OR ROTATION PERIOD.

DIFFERENCE = THE DIFFERENCE BETWEEN THE ENTITLED PROPORTION AVAILABLE AT THE HEAD AND THE ACTUAL VOLUME DELIVERED TO THE SUB-BRANCH

* and ** NOTE THAT SOME WATER WAS DELIVERED TO A-M IN LATE MAY AFTER ROTATION #2 AND AFTER THE A-M MAIN WEIR WAS REMOVED

5.2.3 Analysis

SMIS farmers perceive the existing water allocation principles to be fair and equitable. Farmers also benefit from a high level of involvement of management personnel (who themselves are farmers) in applying the water allocation principles to the distribution of the available water supply. Therefore, the present set of water allocation principles may be considered as an appropriate standard against which to compare actual water distribution and delivery patterns. Therefore, the proportion of water delivered to a branch during a crop season or rotation period should match the proportion of kulara which that branch system possesses.

Table 5.8 clearly indicates that each mauja received its water allocation in terms of the water supplied at the Taraprasad bhod division structure. However, there is significant spatial variation in the delivery of that apportionment of water to the branches in the head, middle and tail areas of the system. Farmers in the head of the system (West Siddhanagar) received water deliveries at their canal inlet which more closely matched their entitlement than did farmers farther down the system from the water source. Therefore, the allocation principle was achieved in terms of apportioning water at the Taraprasad bhod headworks, but the allocation principle does not have a mechanism to compensate for canal conveyance losses which are a significant factor in the dry season.

Conveyance losses in the main canal are very high in proportion to the total flow during the dry season (refer to Section 5.1.3). Consequently, the lower deliveries to the middle and tail areas may be directly attributed to conveyance losses. Data for the two rotation periods confirms that the calculated main canal conveyance losses between Taraprasad bhod and the branch inlets closely match the delivery shortfalls at those points.

Although the delivery of water does not appear to be equitable, a number of factors must be considered:

i) The farmers have no means of accurately measuring flows (the volume of water delivered) at the branches, consequently they allocate water based on time, a method which they manage very accurately.

ii) The irrigation system and the principles on which it functions, were primarily devised to provide water for the staple monsoon rice crop. As Section 5.1.3 shows, canal conveyance losses are much lower during the monsoon, thus fulfilling the equity of the water allocation principle at the canal inlets as well as at the headworks during that time of year.

iii) Indications by farmers that irrigation water requirements are greater in the head areas than in the tail may offer some explanation as to why the allocation principle has not been contested. This may in fact be an implicit means of built-in equity, although it is difficult to believe the water requirements would vary as significantly as the spatial variation in the dry season deliveries.

iv) Some tail end maujas particularly (such as Khopiya) appear to have been "short-changed" in terms of their water delivery. However, during the winter (crop season 2) period, Khopiya received water on a demand basis. During this time Khopiya farmers expressed no complaints regarding water adequacy. Therefore Khopiya was provided with just enough water to meet its perceived needs, thus maximising overall water use efficiency for the system because main canal conveyance losses were thereby kept to a minimum.

v) Khopiya (and many other tail end) farmers did not cultivate a third crop principally because of their larger landholding size and their agricultural practices. Therefore, the fact that the high conveyance losses in the main canal would have in any case prevented any delivery of their allocation at that time did not appear to be an issue with tail end farmers. These farmers were not prepared to expend the considerable effort required to divert such a small amount of water from the Tinau

River. Tail end farmers were therefore exempted from work to divert water during crop season 3 and did not receive any water. It is not clear whether an improved water supply during the dry season, and a ore efficient delivery system, might result in an increased interest among tail end farmers in cultivating a third crop.

vi) Obvious attempts were made during the periods of most severe water shortage (Rotations #1 and #2 in crop season 3) to overcome conveyance losses and ensure delivery of some reasonable amount of water to each farmer by extending the allocation times of some maujas (refer to Table 5.9 and 5.10). Several tail area maujas resorted to diverting the low main canal flows into middle area branch canals, and routed their water through successive branches, to deliver it to their fields. (This practice would support the construction of a sub-main canal - refer to Section 7.1). In addition, maujas which required less than the water they were entitled tc, gave up their excess water allocation.

Given the above points then, farmers appear to be satisfied with the water allocation principles as they stand, and with the effectiveness of management in maintaining them. If, over time, tail end farmers demand more equity in actual water delivery to their areas, then pressure may be brought to bear on the organization to change the water allocation principles for the dry season or to make the necessary improvements to the canal infrastructure to achieve the same end.

Table 5.11 provides for an evaluation of water allocation versus deliveries within the Anandavan Madhuban sub-branch system. Interestingly, the branch level operates very much like the system level. Water apportionment at the inlet is accurately matched with the water allocation rules on a delivery time basis. As is the case at the system level, delivery at the field level varies considerably according to the distance that a farmer's inlet is from the main canal. It is also very interesting to note that "7 bigha" sub-area farmers were especially successful at procuring a greater volume of water than other farmers within the branch system. The "7 bigha" farmers took water directly from the AM main branch canal, illustrating that better access to water generally results in a better supply.

The access - supply issue is significant as field observations and discussion with management personnel indicate that branch areas which abstract water from the joint Sorha-Chhattis main canal (between Khanya dhunga and Taraprasad bhod - refer to Figure 3.1) are taking a much higher proportion of available water than they should be allocated (Pathak - personal communication, 1989). This problem is difficult to overcome since historically these more recently developed areas have rejected the authority of the Sorha and Chhattis organizations.

Controlling water use in the SMIS continues to challenge the farmers who have established and abide by the allocation principles. In this sense, the power of the organization also becomes a measure of its effectiveness and ultimately of the system's performance.

5.3 Water Adequacy

5.3.1 Definition

Water adequacy is a measure of the ability of the water supply to meet the crop water requirements - both in terms of quantity and timeliness. Water adequacy is not simply a measure of irrigation system performance - but encompasses agriculture and management system performance as well. Agriculture system performance is dependent on water adequacy and reliability to produce multiple crops and target yields. The reliability of the water supply, and particularly the timeliness with which it is delivered to meet the crop water requirements (CWR) at the critical growth stages of the crops in question, is a measure of the performance and effectiveness of the management system.

At the system level, water adequacy has been measured by comparing actual water deliveries to the maujas with the volume necessary to meet the CWR over the crop period (season) in question. At the tertiary level water adequacy has been evaluated by comparing farm water deliveries with the seasonal CWR and by further comparing water deliveries to the CWR at the various stages in the crop's development.

This study has confined quantitative analysis to water adequacy. Reliability and timeliness of water deliveries have been noted qualitatively. This approach is not intended to in any way diminish the importance of the timeliness measure, rather it must be emphasized that further analysis beyond the scope of this study is necessary for timeliness to be evaluated in a quantitative way. For completeness, an approach to assessing timeliness is outlined below.

The timeliness of water delivery is as important to farmers and their crops as the quantity of water delivered. Obviously, water supplied when it is not required by the crop is of no benefit. Studies in Nepal (Chaudary, personal communication, 1989) have shown that delays of more than a few days past the optimum time in delivering the first irrigation after seeding result in substantial reduction in the eventual yields of winter wheat crops. Delays in the supply of water at the beginning of other crop seasons have similar results.

Thus crop stress may be determined as a means of evaluating the performance of adequacy and timeliness. Crop stress is a function of a number of factors, such as; crop type, stage of growth, soil, climate, irrigation system characteristics and economics (Podmore, 1983). In order to prevent excessive crop stress it is necessary to supply irrigation water at the appropriate time and in sufficient quantity. Management of irrigation for maximum crop yield is one possible objective for the operation of the irrigation system. Meeting this objective requires knowledge of the critical periods and the ability to supply water at those times to meet crop needs.

In order to measure the direct effect of crop stress (or water conditions) on yield, a variable is required that both reflects water conditions and is functionally related to yield. The conventional approach is to relate yield to some index of water shortage derived empirically from the field. Such an approach has been developed by IIMI staff using three separate indices reflecting the frequency, duration, and intensity (or severity) of water shortage for rice crops. The extent to which crop yield is depressed due to water stress conditions, or conversely, the benefits gained from improved water conditions, can be estimated from the functional relationships between yield and these three indices (termed "reliability", "resiliency", and "vulnerability"). (Ng, 1987.)

The above approach may perhaps be modified to determine the effects of water stress on yields of non-rice crops. By measuring the soil moisture status and relating it to the soil water retention capacity and the ability of the crop to utilize the water (according to the soil type), parameters such as a water shortage index could be developed.

5.3.2 Data Used

i) Crop reference evapotranspiration (ET_o), adopted from a combination of the observed pan evaporation measurements and the calculated values adopted by the BLGWP (refer to Table 5.12). The ET_o values adopted are compared with other values calculated for use in the Terai area (refer to Table 5.13).

ii) Crop coefficients were derived for the winter wheat, early and late spring maize crops using the FAO method (refer to Section 4.2.1) and are listed in Tables 5.14, 5.15 and 5.16. The corresponding crop curves are included in Figures 5.2, 5.3 and 5.4. Crop coefficients are locally specific but are compared with other local Terai values in Table 5.17.

iii) Crop water requirements for winter wheat, early spring maize and late spring maize were calculated and are listed in Tables 5.18, 5.19 and 5.20.

iv) Observed and historical effective rainfall was calculated and is listed in Table 5.21.

v) The areas cultivated for each crop during the winter (2nd) and spring (3rd) crop seasons for the four sub-areas studied are listed in Tables 5.22 - 5.25.

vi) Summaries of water deliveries versus crop water requirements for wheat (crop season 2 foı each mauja are compiled in Tables 5.26(a) - (d).

vii) Table 5.27 lists the wheat critical growth stages.

viii) The adequacy of the maize (crop season 3) water supply versus crop water requirements is analyzed for both early and late spring maize crops in each mauja in Tables 5.28(a)-(e) and Figures 5.5(a)-(e).

ix) Table 5.29 summarizes periods of maize crop stress for the early and late maize crops in the study areas.

x) Table 5.30 lists the maize critical growth stages.

xi) Branch canal distribution sub-system efficiencies (between the flow measurement structure and the farmers field turnouts) are tabulated in Table 5.6 in Section 5.1.

xii) Detailed irrigation records for the wheat crop (season 2) for 68 farmers in the four study areas for West Siddhanagar, Anandavan Madhuban #10 and 7 bigha branches, and Khopiya are included in Appendix B. Detailed individual irrigation application forms are under seperate cover. Irrigation water deliveries were measured and evaluated for the winter wheat (crop season 2) and the early and late spring maize (crop season 3) crops.

Table 5.12 Adopted average ET_o Values

MONTH	ET_o-Penman[1] (mm/month)	ET_o-Pan[2] (mm/month)	Adopted Average ET_o[3]	
			(mm/month)	(mm/day)
January	59	38	49	1.58
February	81	58	70	2.50
March	143	114	129	4.16
April	177	170	173	5.77
May	195	171	183	5.90
June	195	152	174	5.90
July	155	-	130	4.20
August	143	-	-	-
September	120	-	-	-
October	109	-	-	-
November	87	-	61	2.03
December	56	39	48	1.55

Notes:

[1] Penman ET_o values calculated on a monthly basis by the Bhairawa Lumbini Groundwater Project (BLGWP) from historical climatological data.

[2] Pan ET_o values measured in the study area using a Class A evaporation pan.

[3] Adopted average ET_o values are the average of the Penman and Pan values, and were used as the basis for calculating crop water requirements in this study.

Table 5.13 Comparison of ET_o values

MONTH	ET_o (mm/month)					
	WECS[1]		BLGWP[2]		Pan	Adopted
	Penman	Modified Penman	Combined[3]	Penman		
January	60.1	61.1	77.5	58.9	38.0	49.0
February	76.4	79.2	93.3	81.2	58.0	70.0
March	138.3	145.8	155.0	142.6	114.2	129.0
April	210.1	222.3	181.0	177.0	169.5	173.0
May	236.2	251.2	206.7	195.3	170.7	183.0
June	202.3	214.9	170.0	195.3	152.1	174.0
July	166.1	170.0	144.7	155.0	-	-
August	155.8	160.7	142.6	142.6	-	-
September	134.5	139.4	122.0	120.0	-	-
October	117.1	122.8	115.7	108.5	-	-
November	86.9	89.3	104.0	87.0	-	61.0
December	61.4	62.3	77.5	55.8	39.2	48.0
TOTAL	1645.2	1719.0	1590.0	1519.2	-	-

Notes:

[1] WECS = Water and Energy Commission Secretariat (Nepal)

[2] BLGWP = Bhairawa Lumbini Groundwater Project

[3] Combined values are the average of Penman, Blaney-Criddle, and Hargreaves-Christiansen.

Table 5.14 Calculated Crop Coefficients (K_c) for Winter Wheat[1] in the SMIS

Crop Period	Days Since Planting	K_c (10 day)	K_c (month)
0 - 10		0.34	
10 - 20	0 - 30	0.41	0.41
20 - 30		0.47	
30 - 40		0.83	
40 - 50	30 - 60	1.06	1.06
50 - 60		1.15	
60 - 70		1.18	
70 - 80	60 - 90	1.16	1.16
80 - 90		1.10	
90 - 100		0.94	
100 - 110	90 - 120	0.66	
110 - 120		0.34	0.66

Note:
[1] December through March

Table 5.15 Calculated Crop Coefficients (K_c) for Early Spring Maize in the SMIS

Crop Period	Days Since Planting	K_c (10 day)	K_c (month)
0 - 10		0.29	
10 - 20	0 - 30	0.33	0.33
20 - 30		0.47	
30 - 40		0.73	
40 - 50	30 - 60	0.99	0.99
50 - 60		1.14	
60 - 70		1.16	
70 - 80	60 - 90	0.99	0.99
80 - 90		0.84	

Note:
[1] mid-February through mid-March

Table 5.16 Calculated Crop Coefficients (K_c) for Late Spring Maize[1] in the SMIS

Crop Period	Days Since Planting	K_c (10 day)	K_c (month)
0 - 10		0.17	
10 - 20	0 - 30	0.22	0.22
20 - 30		0.35	
30 - 40		0.67	
40 - 50	30 - 60	0.97	0.97
50 - 60		1.12	
60 - 70		1.18	
70 - 80	60 - 90	1.12	1.12
80 - 90		0.84	

Note:
[1] April through June

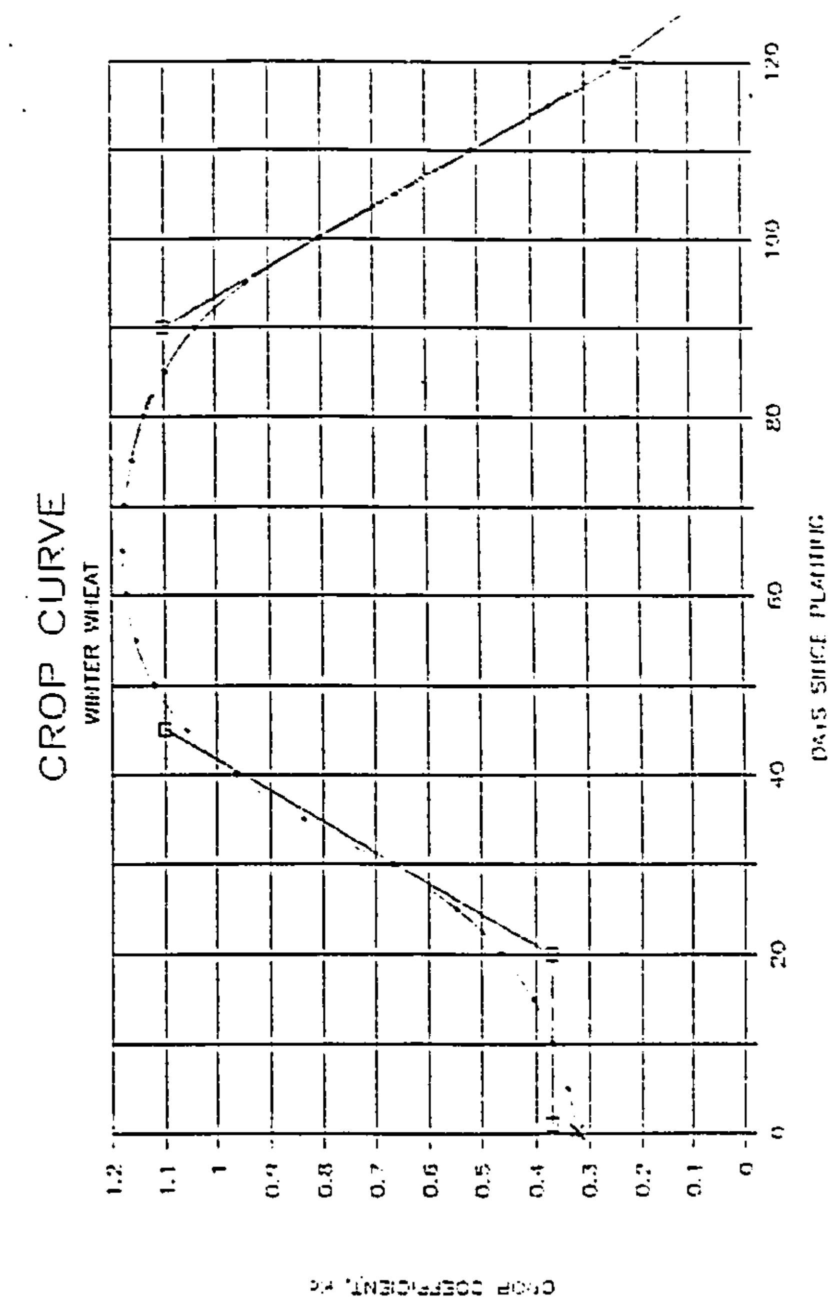


Figure 5.2 Calculated crop coefficient curve for wheat in the SMIS

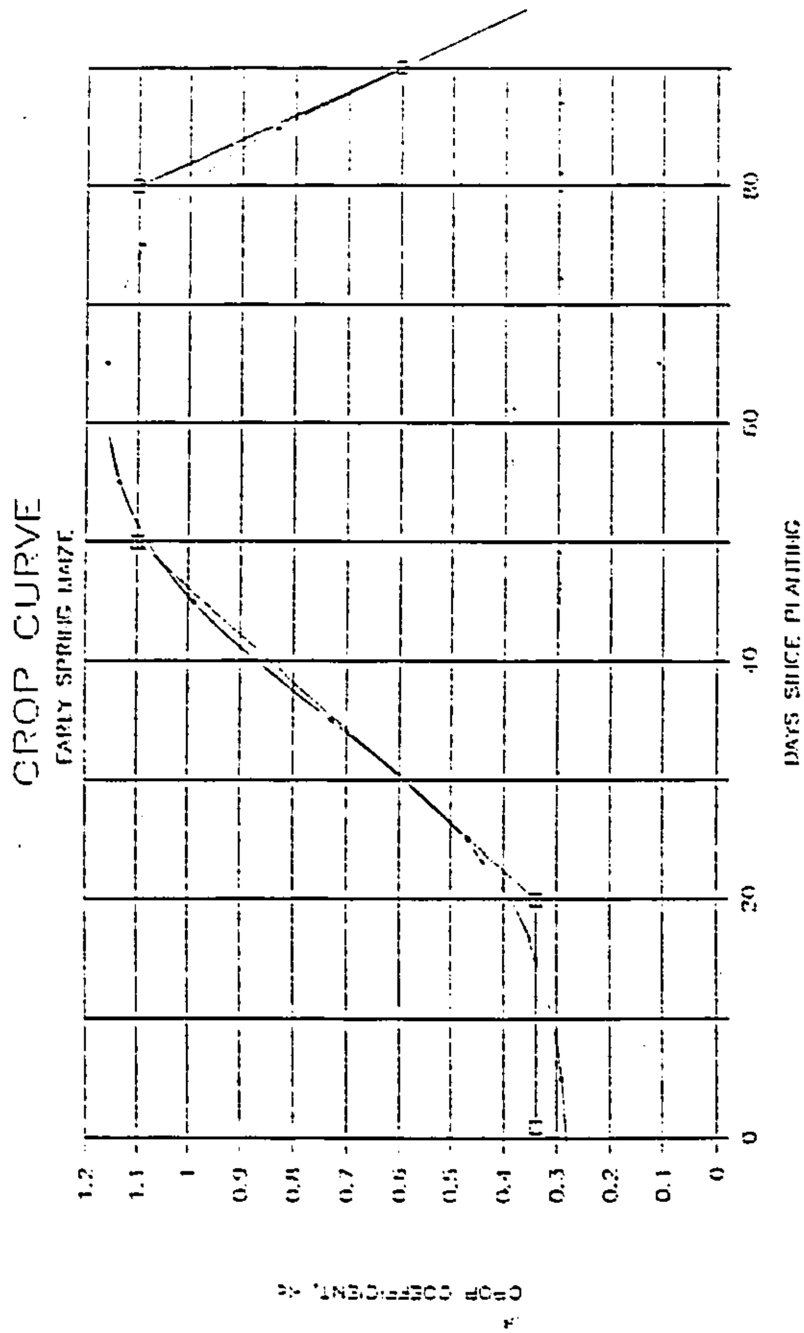


Figure 5.3 Calculated crop coefficient curve for early spring maize in the SMIS

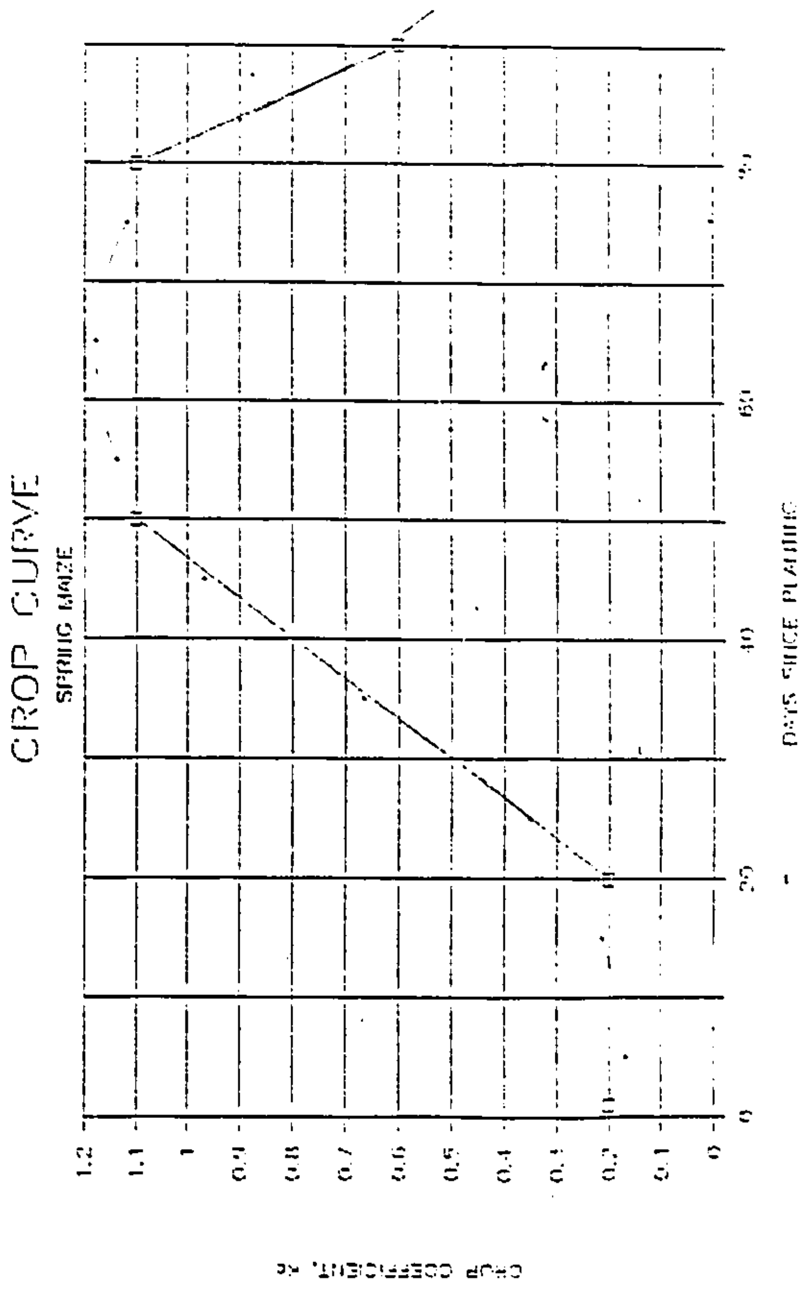


Figure 5.4 Calculated crop coefficient curve for late spring maize in the SMIS

Table 5.17 Comparison of winter wheat crop coefficients

Month	SMIS[1]	BLGWP[2]
December	0.41	0.51
January	1.06	0.95
February	1.16	1.05
March	0.66	0.68

Notes:
[1] Sorha mauja irrigation system

[2] Bhairawa Lumbini Groundwater System

Table 5.18 Crop water requirements for SMIS winter wheat

PERIOD	KC		ETO	CWR		
	10 DAY	MONTH		10 DAY (mm)	10D SUM (mm)	MONTH (mm)
0–10	0.34		48	5		
10–20	0.41	0.41	48	7		20
20–30	0.47		48	8	20	
30–40	0.83		49	14		
40–50	1.06	1.06	49	17		52
50–60	1.15		49	19	50	
60–70	1.18		70	28		
70–80	1.16	1.16	70	27		81
80–90	1.1		70	26	80	
90–100	0.94		129	40		
100–110	0.66	0.66	129	28		85
110–120	0.37		129	16	85	
TOTAL CWR (SEASONAL)					234	

Note:

PERIOD: DECEMBER THROUGH MARCH (120 DAYS)

Table 5.19 Crop water requirements for SMIS early spring maize

PERIOD	KC		ETO	CWR		
	10 DAY	MONTH		10 DAY (mm)	10D SUM (mm)	MONTH (mm)
0–10	0.29		70	7		
10–20	0.33	0.33	129	14		43
20–30	0.47		129	20	41	
30–40	0.73		129	31		
40–50	0.99	0.99	173	57		171
50–60	1.14		173	66	154	
60–70	1.16		173	67		
70–80	0.99	0.99	183	60		181
80–90	0.84		183	51	179	
TOTAL CWR (SEASON)					374	

Note:

PERIOD: MID–FEBRUARY THROUGH MID–MAY (90 DAYS)

Table 5.20 Crop water requirements for SMIS late spring maize

PERIOD	KC 10 DAY	KC MONTH	ETO	CWR 10 DAY (mm)	CWR 10D SUM (mm)	CWR MONTH (mm)
10-20	0.17		173	10		
20-30	0.22	0.22	173	13		38
30-40	0.35		173	20	43	
40-50	0.67		183	41		
50-60	0.97	0.97	183	59		178
60-70	1.14		183	70	170	
70-80	1.18		174	68		
80-90	1.12	1.12	174	65		195
90-100	0.84		174	49	182	
TOTAL CWR (SEASON)					394	

Note:

PERIOD: APRIL THROUGH JUNE (90 DAYS)

Table 5.21 Historical and observed effective rainfall

MONTH	EFFECTIVE RAINFALL[1] (mm)	HISTORICAL[2] RAINFALL (mm)
January	27	12
February	0	11
March	28	14
April	0	20
May	76	49
June	330	257
July	-	452
August	-	293
September	-	287
October	-	77
November	-	4
December	32	12

Notes:

[1] measured locally

[2] annual precipitation with probability of 80% (equal or more) monthly distribution proportional to the average.

Table 5.22 Farm summary for West Siddhanagar branch

Crop Season	Crop	Area Cultivated	Season Intensity Ratio
2	Wheat	3.917	
	Lentil	1.506	
	Aalas	1.390	
	Channa	2.987	
	Maize	0.103	
	Vegetable	0.195	
	Adahar	0.010	
	Tori	0.052	
	Fallow	0.702	
Total		10.862	0.935
3	Maize	4.922	
	Rice/Seed bed	0.119	
	Vegetable	0.105	
	Fallow	5.717	
Total		10.862	0.474

Note:

total land area cultivatable = 10.862 ha

Table 5.23 Farm Summary for Anandavan Madhuban "7 bigha" branch

Crop Season	Crop	Area Cultivated	Season Intensity Ratio
2	Wheat	1.707	
	Lentil	0.516	
	Channa	0.159	
	Vegetable	0.062	
	Adahar	0.021	
	Tori	1.694	
	Fallow	0.020	
Total		4.179	0.995
3	Maize	0.992	
	Rice/Seed bed	0.020	
	Fallow	3.167	
Total		4.179	0.242

Note:

total area cultivatable = 4.179 ha

Table 5.24 Farm summary for Anandavan Madhuban #10 branch

Crop Season	Crop	Area Cultivated	Season Intensity Ratio
2	Wheat	4.681	
	Lentil	3.238	
	Potato	0.053	
	Channa	0.569	
	Maize	0.036	
	Vegetable	0.257	
	Adahar	0.184	
	Barley	0.025	
	Oats	0.037	
	Tori	4.261	
	Fallow	0.223	
Total		13.564	0.984
3	Maize	4.025	
	Rice/Seed bed	0.139	
	Vegetable	0.040	
	Fallow	9.360	
Total		13.564	0.311

Note:

total area cultivatable = 13.564 ha

Table 5.25 Farm summary for Khopiya branch

Crop Season	Crop	Area Cultivated	Season Intensity Ratio
2	Wheat	3.599	
	Lentil	2.184	
	Aalas	1.769	
	Gram	0.017	
	Maize	0.033	
	Fallow	7.780	
Total		15.381	0.494
3	Fallow	15.381	
Total		15.381	0

Notes:

total area cultivatable = 15.381 ha

Table 5.26(a) Summary of water deliveries versus crop water requirements[1] for wheat (crop season 2) for West Siddhanagar farms

Farm Inlet	Total Seasonal Application[2] (mm)	Percent of CWR Applied[3] (%)
1	465	198
2	299	127
3	228	97
4	413	176
5	161	68
6	398	170
8	137	58
9	692	294
10	151	64
11	351	149
12	381	162
14	202	235
16	605	258
18	395	168
19	550	234
20	392	167
21	187	80
22	316	134
23	87	37
25	619	264
26	866	369
27	310	132
28	604	257
Average	383	163

Table 5.26(b) Summary of water deliveries versus crop water requirements[1] for wheat (crop season 2) for Anandavan Madhuban #10 farms

Farm Inlet	Total Seasonal Application[2] (mm)	Percent of CWR Applied[3] (%)
A1/3	244	104
A4	172	73
A5(a)	452	192
A5(b)	397	169
A7	577	246
A8	259	110
A9	119	51
A10	137	58
B1	497	211
B2	323	138
B3/5	183	78
B6	218	93
B7	137	58
B11	269	114
Average	285	121

Table 5.26(c) Summary of water deliveries versus crop water requirements[1] for wheat (crop season 2) for Anandavan Madhuban "7 bigha" farms

Farm Inlet	Total Seasonal Application[2] (mm)	Percent of CWR Applied[3] (%)
1	317	135
2	218	93
3	201	86
7	249	106
Average	246	105

Table 5.26(d) Summary of water deliveries versus crop water requirements[1] for wheat (crop season 2) for Khopiya farms

Farm Inlet	Total Seasonal Application[2] (mm)	Percent of CWR Applied[3] (%)
1	237	101
2	517	220
3	137	58
4	287	122
5	257	109
6	344	147
7	271	115
Average	293	125

Notes:

[1] Total seasonal crop water requirements for all areas = 235 mm.

[2] Includes all irrigation (not adjusted for field and farm ditch losses) and effective rainfall events.

[3] $\frac{\text{Total Seasonal Water Applications}}{\text{Total Seasonal CWR}} \times 100\%$

Table 5.27 Critical growth stages for wheat

Wheat Growth Stage	Days After Planting[1]
Crown root initiation	20-21[2]
Late tillering	40-45
Late jointing	70-75
Flowering	90-95[3]
Milk	101-105
Dough	110-115

Notes:

[1] Growing period = 125-130 days.

[2] Most critical period of the crop development for irrigation, yield decreases if irrigation is later than 25 days.

[3] Second most critical period of crop development for irrigation.

Table 5.28(a) Adequacy of water supplied versus CWR, West Siddhanagar branch, early maize

DATE PERIOD STARTS	DAYS AFTER PLANTING	EVENT OR INTERVAL	ASM AT START (mm)	CWR (– mm)	ADDED MOISTURE (+ mm)	ASM AT END (mm)
02-Apr	0	PLANTING+IRR	50	10	0	40
12-Apr	10	IRR	40	13	158	185
22-Apr	20		185	20	0	165
02-May	30		165	41	0	124
12-May	40	RAIN	124	59	12	77
22-May	50	RAIN+IRR	77	70	215	200
01-Jun	60	RAIN+IRR	200	68	182	200
11-Jun	70	RAIN	200	65	111	200
21-Jun	80	RAIN	200	49	200	200
01-Jul	90	HARVEST	200			

Notes:

- MOISTURE HOLDING CAPACITY OF THE ROOT ZONE = 200 mm OF WATER
- CROP STRESS BEGINS WHEN ASM FALLS BELOW 100 mm
- ASM = AVAILABLE SOIL MOISTURE
- ASSUME ASM AT THE PLANTING DATE = 25% = 50 mm
- IF ASM < 0, ASM = 0

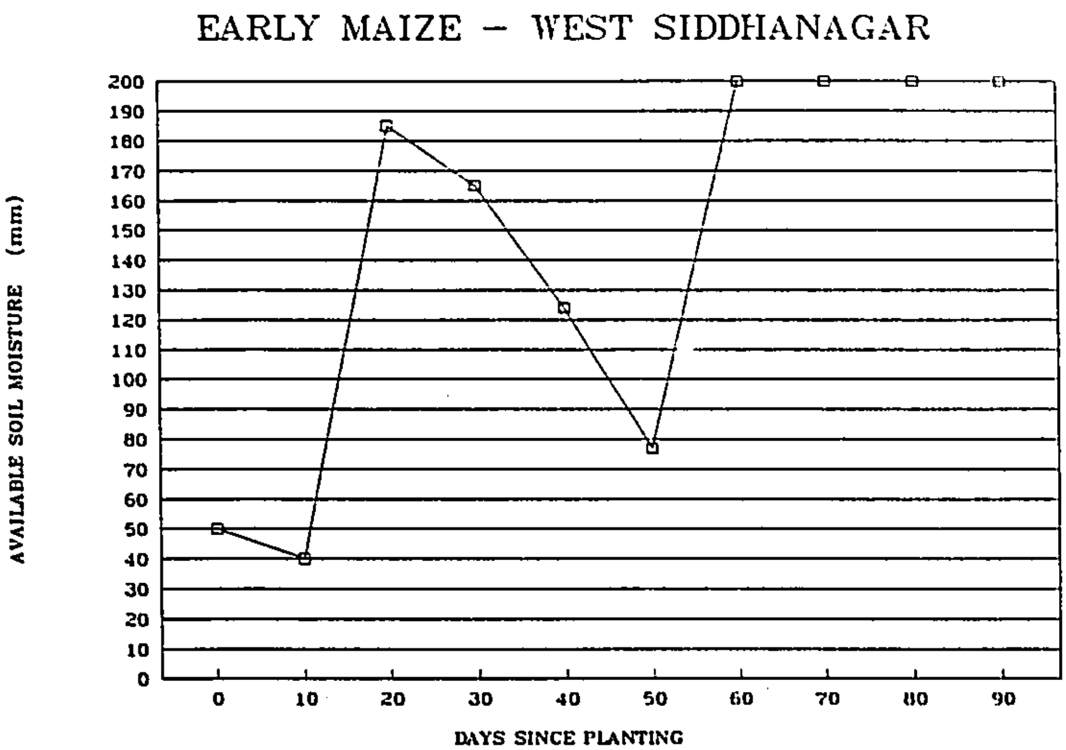


Figure 5.5(a) Adequacy of water supplied versus CWR, West Siddhanagar branch, early maize

Table 5.28(b) Adequacy of water supplied versus CWR, West Siddhanagar branch, late maize

DATE PERIOD STARTS	DAYS AFTER PLANTING	EVENT OR INTERVAL	ASM AT START (mm)	CWR (- mm)	ADDED MOISTURE (+ mm)	ASM AT END (mm)
24-Apr	0	PLANTING+IRR	0	10	158	148
04-May	10		148	13	0	135
14-May	20		135	21	28	142
24-May	30	RAIN+IRR	142	41	215	200
03-Jun	40	RAIN+IRR	200	56	193	200
13-Jun	50	RAIN	200	66	100	200
23-Jun	60	RAIN	200	68	285	200
03-Jul	70	RAIN	200	49	296	200
13-Jul	80	RAIN	200	36	265	200
23-Jul	90	HARVEST	200			

Notes:

- MOISTURE HOLDING CAPACITY OF THE ROOT ZONE = 200 mm OF WATER
- CROP STRESS BEGINS WHEN ASM FALLS BELOW 100 mm
- ASM = AVAILABLE SOIL MOISTURE
- ASSUME ASM AT THE PLANTING DATE = 0% = 0 mm
- IF ASM < 0, ASM = 0

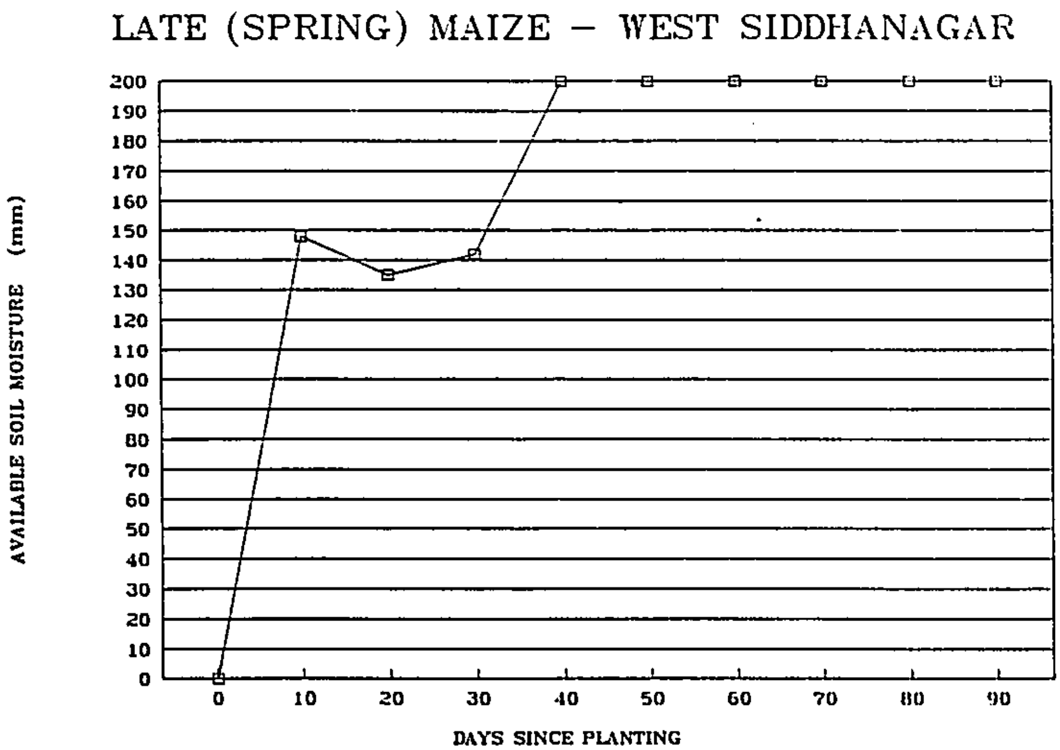


Figure 5.5(b) Adequacy of water supplied versus CWR, West Siddhanagar branch, late maize

Table 5.28(c) Adequacy of water supplied versus CWR, Anandavan Madhuban #10 branch, early maize

DATE PERIOD STARTS	DAYS AFTER PLANTING	EVENT OR INTERVAL	ASM AT START (mm)	CWR (– mm)	ADDED MOISTURE (+ mm)	ASM AT END (mm)
14-Feb	0	PLANTING	150	7	0	143
24-Feb	10		143	14	0	129
06-Mar	20	RAIN	129	20	28	137
16-Mar	30		137	31	0	106
26-Mar	40		106	57	0	49
05-Apr	50	IRR	49	66	138	121
15-Apr	60		121	67	0	54
25-Apr	70		54	60	0	0
05-May	80	RAIN+IRR	0	51	43	0
15-May	90	HARVEST	0			

Notes:

- MOISTURE HOLDING CAPACITY OF THE ROOT ZONE = 200 mm OF W
- CROP STRESS BEGINS WHEN ASM FALLS BELOW 100 mm
- ASM = AVAILABLE SOIL MOISTURE
- ASSUME ASM AT THE PLANTING DATE = 75% = 150 mm
- IF ASM < 0, ASM = 0

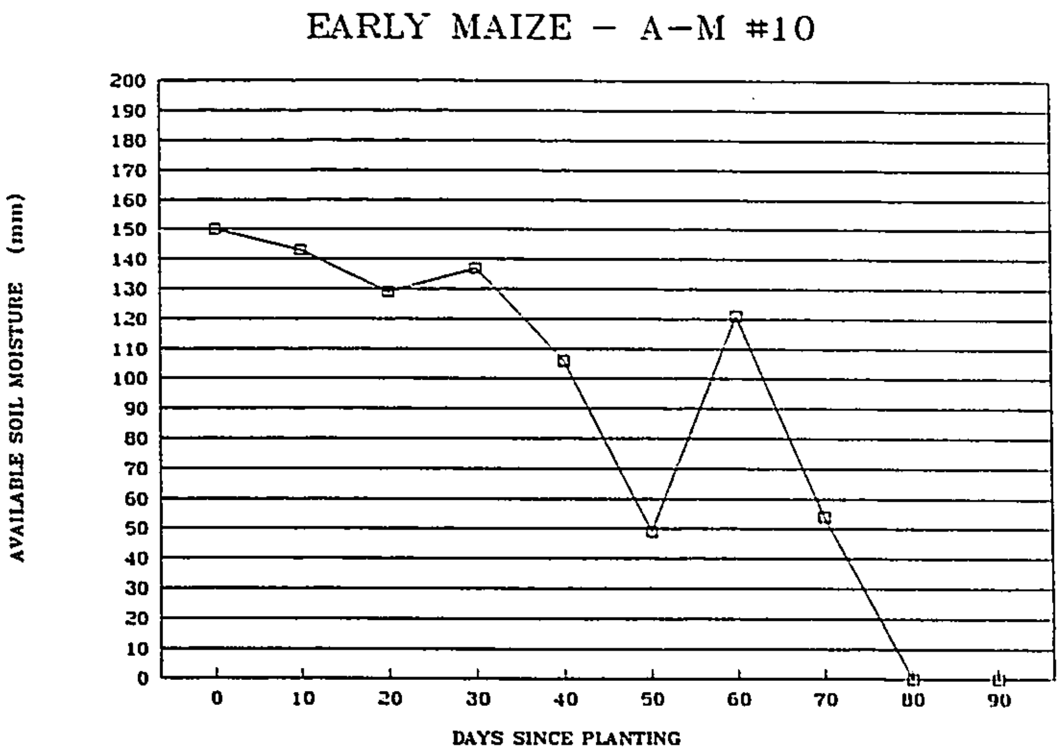


Figure 5.5(c) Adequacy of water supplied versus CWR, Anandavan Madhuban #10 branch, early maize

Table 5.28(d) Adequacy of water supplied versus CWR, Anandavan Madhuban #10 branch, late maize

DATE PERIOD STARTS	DAYS AFTER PLANTING	EVENT OR INTERVAL	ASM AT START (mm)	CWR (– mm)	ADDED MOISTURE (+ mm)	ASM AT END (mm)
08–Apr	0	PLANTING	50	10	0	40
18–Apr	10	IRR	40	13	138	165
28–Apr	20		165	20	0	145
08–May	30	RAIN+IRR	145	41	43	147
18–May	40	RAIN	147	59	47	135
28–May	50	RAIN	135	70	59	124
07–Jun	60	RAIN	124	68	33	89
17–Jun	70	RAIN	89	65	190	200
27–Jun	80	RAIN	200	49	270	200
07–Jul	90	HARVEST	200			

Notes:

- MOISTURE HOLDING CAPACITY OF THE ROOT ZONE = 200 mm OF WA
- CROP STRESS BEGINS WHEN ASM FALLS BELOW 100 mm
- ASM = AVAILABLE SOIL MOISTURE
- ASSUME ASM AT THE PLANTING DATE = 25% = 50 mm
- IF ASM < 0, ASM = 0

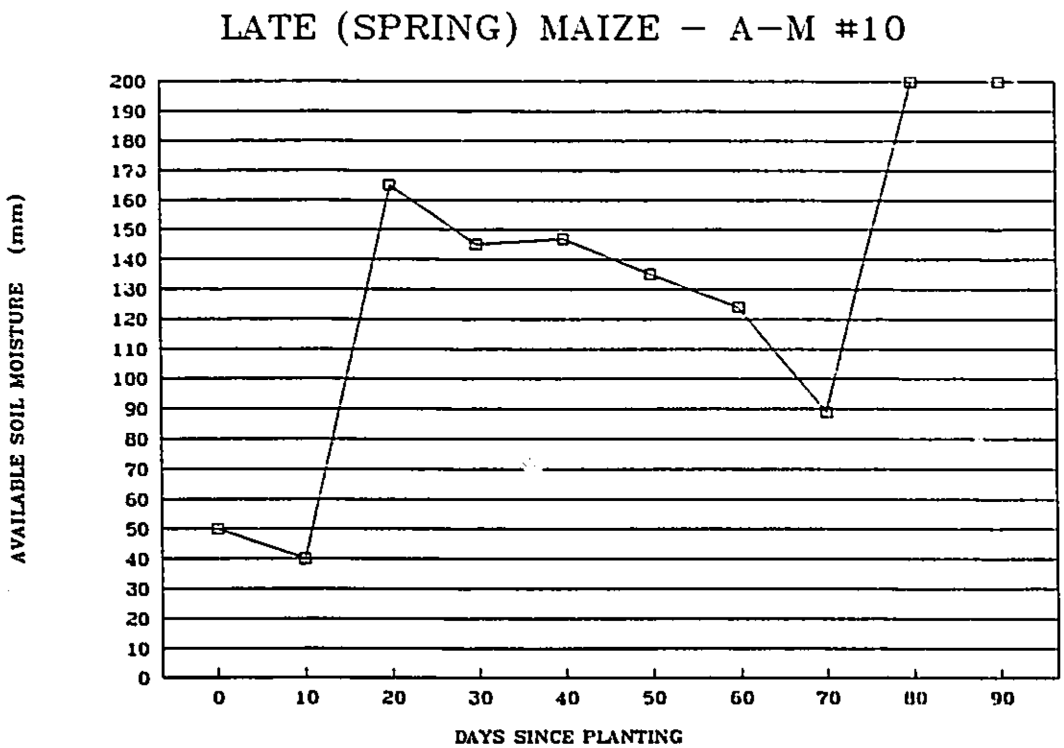


Figure 5.5(d) Adequacy of water supplied versus CWR, Anandavan Madhuban #10 branch, late maize

Table 5.28(e) Adequacy of water supplied versus CWR, Anandavan Madhuban "7 bigha" branch, early maize

DATE PERIOD STARTS	DAYS AFTER PLANTING	EVENT OR INTERVAL	ASM AT START (mm)	CWR (– mm)	ADDED MOISTURE (+ mm)	ASM AT END (mm)
17-Feb	0	PLANTING	150	7	0	143
27-Feb	10		143	14	0	129
09-Mar	20	RAIN	129	20	28	137
19-Mar	30		137	31	0	106
29-Mar	40		106	57	0	49
08-Apr	50	IRR	49	66	209	192
18-Apr	60		192	67	0	125
28-Apr	70		125	60	0	65
08-May	80	RAIN+IRR	65	51	110	124
18-May	90	HARVEST	124			

Notes:

- MOISTURE HOLDING CAPACITY OF THE ROOT ZONE = 200 mm OF WAT
- CROP STRESS BEGINS WHEN ASM FALLS BELOW 100 mm
- ASM = AVAILABLE SOIL MOISTURE
- ASSUME ASM AT THE PLANTING DATE = 75% = 150 mm
- IF ASM < 0, ASM = 0

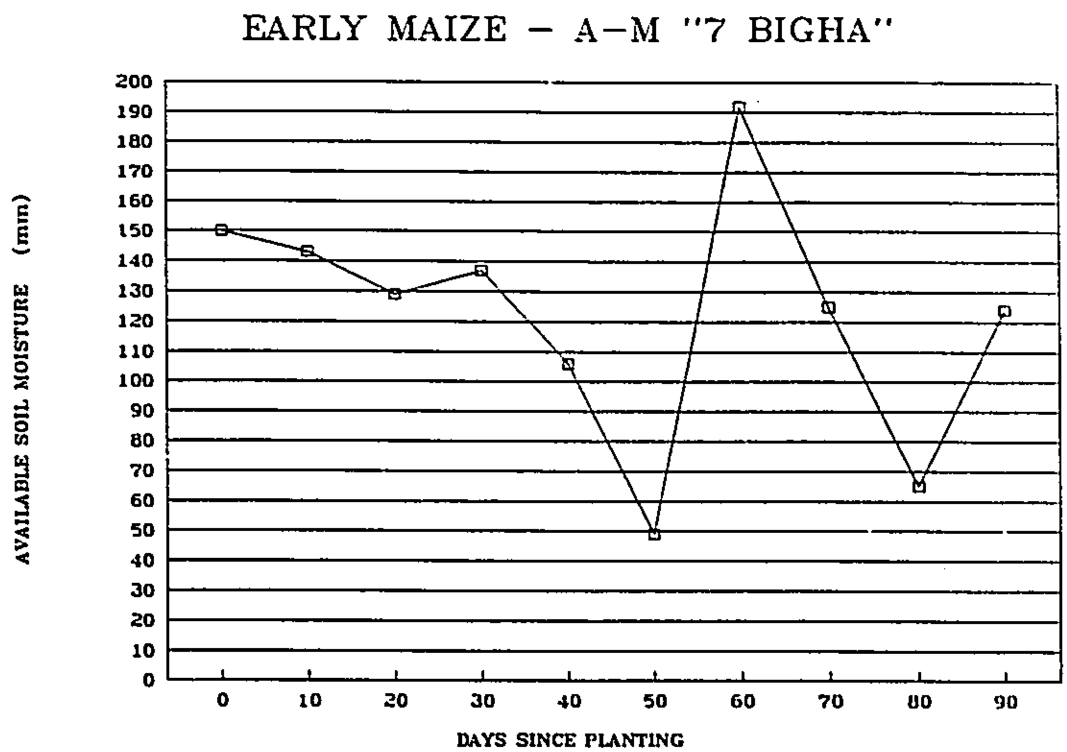


Figure 5.5(e) Adequacy of water supplied versus CWR, Anandavan Madhuban "7 bigha", early maize

Table 5.29 Summary of maize crop stress

Mauja	Crop	Stress Period(s) (Day Nos.)	Stress Days (No. of)
West Siddhanagar	early maize	1-14 45-52	21
West Siddhanagar	late maize	1-7	7
Anandavan Madhuban #10	early maize	41-58 63-80	34
Anandavan Madhuban #10	late maize	0-15 67-71	19
Anandavan Madhuban "7 bigha"	early maize	41-53 74-87	25

Table 5.30 Critical growth stages for maize

Maize Growth Stage	Days After Planting
before tasselling	
during tasselling and silking	
after formation	
after pollination	
ear formation (early grain)	
flowering	65-70
milk	80

5.3.3 Analysis

The crop reference evapotranspiration (ET_o) and crop coefficient (K_c) values calculated for use in this analysis were similar to those used in other studies of irrigation systems in the Terai (refer to Table 5.13).

Effective rainfall P_e during the 1988-89 winter and spring crop seasons varied somewhat from historical average values (refer to Table 5.21). Evaluation of the historical data has shown that this variation is typical during the "dry season" months. Rainfall during the monsoon season (June through September) tends to be much more consistent. Consequently, P_e provided only marginally to the crop water requirements of the dry season crops during their critical growth stages.

Almost the entire cultivable area in the upper and middle branches was cropped during the winter (second) season as shown by the crop season intensity ratios in Tables 5.22 - 5.24. Tail end areas (such as Khopiya) planted only a proportion of the cultivatable land (refer to Table 5.25). This spatial variation in the cropping intensity for the second crop was, according to farmers, more an issue of cultural practises and landholding size than one of water adequacy.

Assessment of the seasonal CWR versus the total seasonal water application (irrigation delivery and effective rainfall combined) for the winter wheat crop shows a significant majority of farmers in all areas met or exceeded their respective CWR (refer to Tables 5.26(a) - (d). Examination of yield versus the seasonal water supply (refer to Figures 5.6 and 5.7) provides further confirmation that the water supply was adequate for all areas planted to wheat. Figure 5.6 and 5.7 show no correlation between irrigation water supply and yield. Therefore, variation in yield must be due to other factors such as fertilizer use and other agricultural practices, or soil fertility for example. Yields for wheat were above local, regional and national levels (as discussed in Section 5.4.3). It should be noted that some farmers reported yields that were much less than measured yields (compare Figure 5.6 with 5.7). Since the water supply was significantly more than adequate for wheat and yields were high, crop stress could not have been significant and was not studied in further detail. Water supply was available on demand during this period, and the irrigation records indicate that farmers were successful in providing timely irrigation applications at the critical growth stages of the wheat crop.

Further analysis was made to determine if the available water supply might have permitted more intensive crop cultivation during that period. Tables 5.31(a) - (d) assess the potential

Table 5.31 Assessment for potential to increase the irrigation area for wheat in season 2

CROP: WHEAT
AREA: WEST SIDDHANAGAR 10.862 HA

PERIOD	HIST. RAIN (mm)	CWR (mm)	NET CWR (mm)	AREA (ha)	REQ'D @ FIELD (ha-m)	SYSTE EFF.	REQ'D @ HEAD (ha-m)	ALLOC. @ HEAD (ha-m)	ADEQUAC (%)	CONV. EFF.	AV. MAIN FLOW	DIST. (km)	KUL.
DECEMBE	13	120	107	10.9	1.458	85%	1.716	3.085	180%	95%	0.738	0.5	1.5
JANUARY	12	50	38	10.9	0.518	84%	0.615	2.579	419%	95%	0.617	0.5	1.5
FEBRUARY	11	80	69	10.9	0.940	83%	1.130	2.140	189%	93%	0.512	0.5	1.5
MARCH	14	85	71	10.9	0.967	81%	1.190	1.622	136%	91%	0.388	0.5	1.5

POTENTIAL CROPPED AREA = 100%

CROP: WHEAT
AREA: A-M #10 13.564 HA

PERIOD	HIST. RAIN (mm)	CWR (mm)	NET CWR (mm)	AREA (ha)	REQ'D @ FIELD (ha-m)	SYSTE EFF.	REQ'D @ HEAD (ha-m)	ALLOC. @ HEAD (ha-m)	ADEQUAC (%)	CONV. EFF.	AV. MAIN FLOW	DIST. (km)	KUL.
DECEMBE	13	120	107	8.7	1.164	51%	2.281	4.114	182%	75%	0.738	2.8	2
JANUARY	12	50	38	8.7	0.413	48%	0.861	3.439	400%	70%	0.617	2.8	2
FEBRUARY	11	80	69	8.7	0.750	44%	1.716	2.854	166%	63%	0.512	2.8	2
MARCH	14	85	71	8.7	0.772	36%	2.167	2.163	100%	52%	0.388	2.8	2

POTENTIAL CROPPED AREA = 64%

Table 5.31 (cont) Assessment for potential to increase the irrigation area for wheat in season 2

CROP: WHEAT
AREA: A-M 7 BIGHA 4.179 HA

PERIOD	HIST. RAIN (mm)	CWR (mm)	NET CWR (mm)	AREA (ha)	REQ'D @ FIELD (ha-m)	SYSTE EFF.	REQ'D @ HEAD (ha-m)	ALLOC. @ HEAD (ha-m)	ADEQUAC (%)	CONV. EFF.	AV. MAIN FLOW	DIST. (km)	KUL.
DECEMBE	13	120	107	2.18	0.292	51%	0.567	1.028	182%	75%	0.738	2.8	0.5
JANUARY	12	50	38	2.18	0.104	48%	0.218	0.860	399%	70%	0.617	2.8	0.5
FEBRUARY	11	80	69	2.18	0.188	44%	0.430	0.713	166%	63%	0.512	2.8	0.5
MARCH	14	85	71	2.18	0.193	36%	0.543	0.541	100%	52%	0.388	2.8	0.5

POTENTIAL CROPPED AREA = 52%

CROP: WHEAT
AREA: KHOPIYA 15.381 HA

PERIOD	HIST. RAIN (mm)	CWR (mm)	NET CWR (mm)	AREA (ha)	REQ'D @ FIELD (ha-m)	SYSTE EFF.	REQ'D @ HEAD (ha-m)	ALLOC. @ HEAD (ha-m)	ADEQUAC (%)	CONV. EFF.	AV. MAIN FLOW	DIST. (km)	KUL.
DECEMBE	13	120	107	1.5	0.201	31%	0.639	2.057	322%	38%	0.738	6.8	1
JANUARY	12	50	38	1.5	0.071	21%	0.332	1.720	518%	26%	0.617	6.8	1
FEBRUARY	11	80	69	1.5	0.129	9%	1.432	1.427	100%	11%	0.512	6.8	1
MARCH	14	85	71	1.5	0.133	0%	+++	1.081		0%	0.388	6.8	1

POTENTIAL CROPPED AREA = 10%

- ASSUME FIELD APPL. EFFICIENCY = 20 % FOR ALL AREAS
- DISTRIBUTION EFFICIECIES = 89 % WEST SIDDHANAGAR
  69 % ANANDAVAN MADHUBAN
  82 % KHOPIYA
- CONVEYANCE EFFICIENCIES = BASED ON FLOW & LOSSES OF 0.067 m^3/s/km
- ASSUME CWR INCLUDES 100mm IN THE FIRST MONTH FOR PRE-IRRIGATION
- HISTORICAL RAINFALL, 80% EXCEEDENCE USED

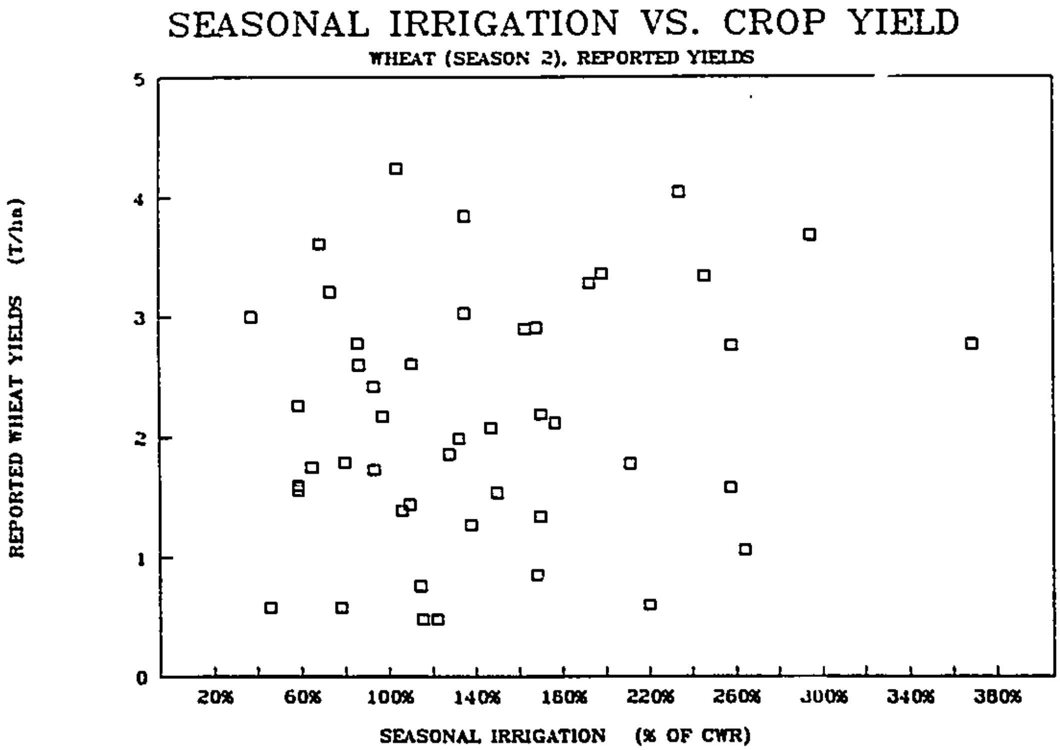


Figure 5.6 Irrigation versus reported crop yield for wheat (season 2)

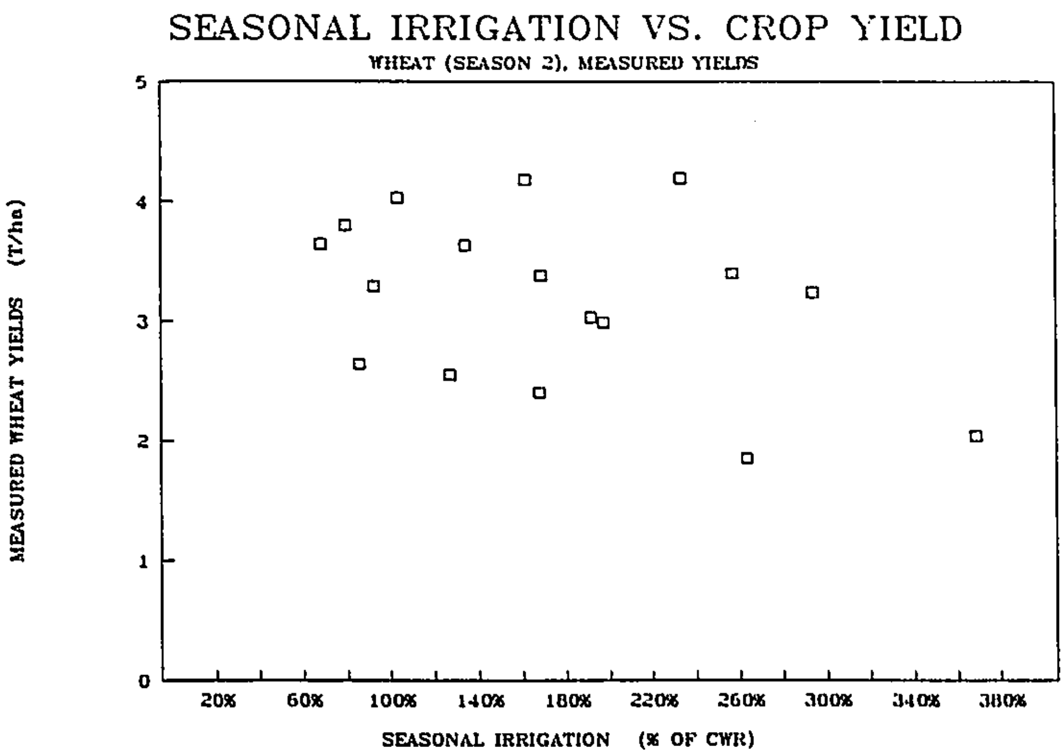


Figure 5.7 Irrigation versus measured crop yield for wheat (season 2)

Table 5.32 Potential area irrigable for wheat (crop season 2) versus the proportion of area cultivated

Mauja	Area (% of total)	
	Irrigable for wheat[1]	Cultivated for All Crops[2]
West Siddhanagar	100	94
Anandavan Madhuban #10	64	100
Anandavan Madhuban "7 bigha"	52	98
Khopiya	<10	49

Notes:

[1] From Table 5.31

[2] From Tables 5.22 - 5.25

for cultivating a larger proportion of the cultivable land in the SMIS to wheat during crop season 2. The potential area irrigable is compared with the actual area cultivated to all crops in Table 5.32. Farmers appear to have received an adequate water supply to be able to maximize the actual cropping intensity in the head (West Siddhanagar) and middle (Anandavan Madhuban) areas. The water supply was not sufficient to irrigate a more substantial proportion of cultivable area in the tail end of the SMIS system (Khopiya). However, several points of interest should be made here:

i) A larger area is irrigable to wheat in the middle and tail areas if it is planted two to four weeks earlier, in November.

ii) The fact that Khopiya farmers actually cultivated 23% of their area to wheat (that is 47% of their area cropped - refer to Table 5.25) in contrast to the potential area of <10% (refer to Table 5.32) indicates that:
   - the efficiency assumptions in Table 5.31 are too conservative,
   - groundwater contribution to CWR is significant, or
   - farmers provided sufficient irrigation water to the soil in February to carry over into March.

iii) Farmers did not crop a greater proportion of land to wheat during the second crop period, but chose to plant other crops (some of which have much lower CWR than wheat) or leave some land fallow indicates that other important factors were influencing farmers decisions regarding their cropping pattern and intensity. Farmers' decisions regarding the crops cultivated during the second (winter) crop period may have been affected by unattractive pricing and/or poor markets for additional wheat production, or other crops such as lentils may have been more profitable and/or may have been preferable for domestic consumption.

The available water supply may have been utilized to grow a larger proportion of the area planted to all crops, to wheat, if farmers in the head and middle areas had so desired. Farmers in the tail area appear to have no potential to expand their cropped area in season 2 unless they seed earlier (in October and November), in which case they are constrained by poor soil drainage conditions after the monsoon.

The maize crop was planted during the driest period of the year (late March through April. Consequently, maize was subject to stress during its growing season (until late May) by a lack of rainfall, by long irrigation application intervals, and because of the very limited water supply. Stress periods are derived for each maize crop in Tables 5.28(a) - (e), are illustrated in Figures 5.5(a) - (e), and are summarized in Table 5.30.

Farmers planted only a very limited area to the third (maize) crop, ranging from 47 percent of cultivable area in West Siddhanagar to 0 percent in Khopiya (refer to Tables 5.22 - 5.25). Farmers complained of an inadequate water supply during April through mid-May, and of rain begining later than usual in May. Undoubtedly the most severe maize crop stress occurred during the first three weeks of May before the first pre-monsoon rains began. Maize planted at the end of April without an adequate pre-irrigation experienced severe stunting. Reported yield varied widely and is indicative of the variation in farmers' individual planting dates of the maize crop. Table 5.33 (in comparison with Tables 5.22 - 5.25) illustrates that farmers could not expand the area cropped to maize (season 3) without an improved water supply during the months of April and May.

Table 5.33 Assessment of the potential to increase the irrigated area for maize in season 3

CROP: MAIZE
AREA: WEST SIDDHANAGAR 10.862 HA

PERIOD	HIST. RAIN (mm)	CWR (mm)	NET CWR (mm)	AREA (ha)	REQ'D @ FIELD (ha-m)	SYSTE EFF.	REQ'D @ HEAD (ha-m)	ALLOC. @ HEAD (ha-m)	ADEQUAC (%)	CONV. EFF.	AV. MAIN FLOW	DIST. (km)	KUL.
APRIL	20	143	123	5.85	0.899	78%	1.150	1.154	100%	88%	0.276	0.5	1.5
MAY	49	170	121	5.85	0.885	82%	1.084	1.697	157%	92%	0.406	0.5	1.5
JUNE	257	182	0	5.85	0.000	86%	0.000	4.218	100% +	97%	1.009	0.5	1.5

POTENTIAL CROPPED AREA = 54%

CROP: MAIZE
AREA: A-M #10 13.584 HA

PERIOD	HIST. RAIN (mm)	CWR (mm)	NET CWR (mm)	AREA (ha)	REQ'D @ FIELD (ha-m)	SYSTE EFF.	REQ'D @ HEAD (ha-m)	ALLOC. @ HEAD (ha-m)	ADEQUAC (%)	CONV. EFF.	AV. MAIN FLOW	DIST. (km)	KUL.
APRIL	20	143	123	2.22	0.341	22%	1.544	1.538	100%	32%	0.276	2.8	2
MAY	49	170	121	2.22	0.338	37%	0.905	2.263	250%	54%	0.406	2.8	2
JUNE	257	182	0	2.22	0.000	56%	0.000	5.624	100% +	81%	1.009	2.8	2

POTENTIAL CROPPED AREA = 16%

Table 5.33 (cont) Assessment of the potential to increase the irrigated area for maize in season 3

CROP: MAIZE
AREA: A-M 7 BIGHA 4.179 HA

PERIOD	HIST. RAIN (mm)	CWR (mm)	NET CWR (mm)	AREA (ha)	REQ'D @ FIELD (ha-m)	SYSTE EFF.	REQ'D @ HEAD (ha-m)	ALLOC. @ HEAD (ha-m)	ADEQUAC (%)	CONV. EFF.	AV. MAIN FLOW	DIST. (km)	KUL.
APRIL	20	143	123	0.56	0.086	22%	0.390	0.385	99%	32%	0.276	2.8	0.5
MAY	49	170	121	0.56	0.085	37%	0.228	0.566	248%	54%	0.406	2.8	0.5
JUNE	257	182	0	0.56	0.000	56%	0.000	1.406	100% +	81%	1.009	2.8	0.5

POTENTIAL CROPPED AREA = 13%

CROP: MAIZE
AREA: KHOPIYA 15.381 HA

PERIOD	HIST. RAIN (mm)	CWR (mm)	NET CWR (mm)	AREA (ha)	REQ'D @ FIELD (ha-m)	SYSTE EFF.	REQ'D @ HEAD (ha-m)	ALLOC. @ HEAD (ha-m)	ADEQUAC (%)	CONV. EFF.	AV. MAIN FLOW	DIST. (km)	KUL.
APRIL	20	143	123	1.5	0.231	0%	+++	0.769	0%	−65%	0.276	6.8	1
MAY	49	170	121	1.5	0.227	0%	+++	1.132	0%	−12%	0.406	6.8	1
JUNE	257	182	0	1.5	0.000	45%	0.000	2.812	100% +	55%	1.009	6.8	1

POTENTIAL CROPPED AREA = 10%

- ASSUME FIELD APPL. EFFICIENCY = 20 % FOR ALL AREAS
- DISTRIBUTION EFFICIECIES = 89 % WEST SIDDHANAGAR
  69 % ANANDAVAN MADHUBAN
  82 % KHOPIYA
- CONVEYANCE EFFICIENCIES = BASED ON FLOW & LOSSES OF 0.067 m^3/s/km
- ASSUME CWR INCLUDES 100mm IN THE FIRST MONTH FOR PRE-IRRIGATION
- HISTORICAL RAINFALL, 80% EXCEEDENCE USED

5.4 Crop Production

5.4.1 Definition

Actual crop production (or yield) on the basis of unit land area or unit volume of water supplied is probably the most common measure of agriculture system performance (within an irrigation system). Although widely applied as a measure of performance, crop production is not easily defined or controlled for the purpose of comparison with standards or targets for production. Measures of crop production have obvious limitations as the collection of the wide range of pertinent data is difficult. Crop yields are influenced by many factors (other than area and water supply) that are difficult to measure and quantify. Such factors include: seed variety, seeding rate, soil fertility, type and rate of fertilizer use, and other agricultural practices. Nevertheless, crop production is an effective means of evaluating the level of output from an irrigation system in a relative way against the production of other irrigation systems or production standards such as regional and national production levels.

The level of crop production in the SMIS was evaluated by measuring the principal dry season crop yields from sample farms as described in Section 4.4.2) and by recording farmers reported yields for all crops.

5.4.2 Data Used

i) Farm information files compiled under separate cover include the reported yields for all crops cultivated by the 68 individual farmers in the four study areas.

ii) Reported rice yields are summarized in Table 5.34.

iii) Measured and reported wheat yields are listed in Table 5.35 and summarized and compared in Table 5.36.

iv) Measured maize yields are reported in Table 5.37(a) and (b).

v) Local (BLGWP), regional (average crop yields from irrigation systems in the Western Terai region), and national average crop yields are summarized in Table 5.38.

vi) Crop sample analysis results from the concurrent IIMI study of the CMIS are listed in Table 5.39.

vii) Analysis of yield versus CWR is made in Section 5.3.3 (refer to Figures 5.6 and 5.7).

Table 5.34 Reported rice yields

Branch Area	Weighted Yield[1] (T/ha)	Average Farm Yield (T/ha)	Minimum Farm Yield (T/ha)	Maximum Farm Yield (T/ha)
W-Sidd	3.18	3.31	0.81	5.08
A-M #10	3.20	3.07	0.78	5.11
A-M 7b	3.21	3.24	2.39	3.93
Khopiya	3.61	3.79	1.96	5.82

Note:

[1] Farmers' yields weighted according to their cropped area.

Table 5.35 Measured and reported wheat yields

SAMPLE FARMER	REPORTED YIELD (T/ha)	MEASURED YIELD (T/ha)
TARAPRASAD NEUPANE	2.90	4.44
J. B. SHAH	2.76	3.60
BHAKTA BAHADUR K.C.	3.68	3.43
RAM BAHADUR CHETTRI	3.36	3.16
SARBAJIT RANA	3.61	3.84
DUMBER BAHADUR PAUDHEL	1.06	1.96
NUR BAHADUR GURUNG	2.77	2.15
HARSHA BAHADUR BHARAL	1.86	2.68
SAMALATA PAUDHEL	1.79	4.02
MUKTI PRASAD PATHAK	1.34	3.48
GIRI RAJ PATHAK	3.28	3.20
BENI MAHDAB ADHIKHARI	1.73	3.48

Table 5.36 Comparison of measured and reported wheat yields

Branch Area	Measured Yield (T/ha)		Reported Yield (T/ha)			
	Average	Error vs. Reported	Weighted	Ave.	Min.	Max.
W-Sidd.	3.08	+22%	2.47	2.40	0.85	4.04
A-M #10	3.48	+36%	2.19	2.24	0.58	4.24
A-M 7b	3.46	+23%	2.63	2.67	-	-
Khopiya	-	-	0.86	1.04	-	-

Table 5.37 Measured maize yields

(a) Monetary yield (West Siddhanagar)

Inlet Number	Area	Number of Cobs	Income	
			(Rs)	(Rs/ha)
1	0.187	900	270	1444
2	0.251	2800	980	3904
3	0.138	-	465	3370
12	0.182	-	298	1637
15	0.077	-	300	3896
19	0.395	-	525	1329
22	0.165	1500	400	2424
27	0.109	775	256	2349
28	0.126	640	205	1627
29	0.239	2150	710	2971

(b) Measured by crop sampling

Farmer	Measured Yield (T/ha)
J.B. Shah	3.370
D.B. Paudyal	2.423
Madhab Pathak	1.979

Note:

Most farmers utilized this crop for domestic food and fodder for cattle

Table 5.38 Local, regional, national and target crop yields for comparison

Crop	Yield (T/ha)			
	BLGWP (3 year average)	Regional	Target	National Average (1987/88)
Rice (local)	1.93	-	-	-
Rice (HYV)	3.92	2.50-2.80	3.00-3.80	2.09
Wheat	2.55	2.20	2.80	1.25
Oilseed	0.74	0.70	0.95	0.62
Lentil (Pulse)	0.86	1.00	1.50	0.39
Maize	2.93	1.80	2.60	1.34

Table 5.39 CMIS measured yields (1988-89)

Crop	No. of Samples	Yield (T/ha)
Rice	22	3.70
Wheat	18	2.87
Maize	13	2.18
Oilseed	11	0.81
Lentil	6	1.08

5.4.3 Analysis

Reported yields are significantly less than measured yields of wheat for the sample farms. However on the whole, average measured values exceed average reported values by 22 to 36 percent. These differences are well outside the possible measurement errors (of approximately 5-10 percent) and may be due to farmers reporting only the portion which was milled commercially or sold, deliberately low reports by some farmers, or simply inaccurate estimates by farmers.

Reported rice yields may be more accurate as rice is the principal crop grown on 100 percent of cultivable land. CMIS reported rice yields of 3.7 T/ha compare closely with average reported rice yields from the four SMIS study areas of 3.1 to 3.8 T/ha. The SMIS rice yields in turn compare favourably with local (BLGWP) yields (3.9 T/ha) and well exceed regional and national average yields (2.8 T/ha and 2.1 T/ha respectively). The performance of the SMIS rice crop is very good, approaching the regional target yield of 3.0-3.8 T/ha used in the preparation of Nepal's Irrigation Master Plan (refer to Table 5.38).

Measured wheat yields from 17 sample farmers provide average yields in three of the study areas of 3.1 to 3.5 T/ha. The performance of the wheat crop is thus excellent as it significantly exceeds even the regional target production level of 2.8 T/ha. Even reported SMIS wheat yields ranging from 2.2 to 2.7 T/ha compare favourably with local (2.55 T/ha), regional (2.2 T/ha) and national average (1.25 T/ha) values for wheat.

Maize yield proved difficult to measure. Maize was grown during the water scarce spring season and much of the crop did not fully develop before farmers cultivated the land for rice and was consequently used as livestock fodder. A large proportion of the maize crop was to be consumed on the farm and thus farmers could not accurately report their yields, Several samples were analyzed and the results included in Table 5.37(b). Measured yields range from 1.9 to 3.3 T/ha. Some farmers simply sold the green cobs and reported the number of cobs sold and the income recorded in Table 5.37(a). Performance of the maize crop on some of the measured and reporting farms appears to have been relatively good.

However, a conclusive assessment cannot be made of the maize data. Field observations would indicate that yields vary widely depending on when the farmer was able to sow the maize and on how much care was given to making timely water applications. Maize is particularly susceptible to crop stress and an inadequate water supply particularly in late April and early May would decrease yields. Water stress during this period affected early maize during its late season maturation phase and late maize during its development stage. Conditions are usually such that planting a third crop of maize is a risky proposition for farmers.

Results indicate a wide variation in average yields between individual farms for all crops. This is indicative of the many independent factors (other than water supply) that affect crop yields. Some farmers are particularly innovative and interested in experimenting with new crop varieties and agricultural practices, while others are much less so. Depending on the particular lease arrangement, many tenant farmers are unwilling to invest significantly in farm inputs. Those farmers who are achieving very high yields should eventually influence their neighbours to adopt their practices. This concept of leadership by example is probably the most effective means of increasing crop production within the physical limitations of the system.

Field observations also indicate a diminishing level of concern on the part of many farmers over the second and third crop periods (particularly for the third, maize, crop). Crop production in the Terai centres around production of the valuable monsoon rice crop. As the return on subsequent crops diminishes, so does the farmers' interest in expending his or her resources in producing them. This factor may in part explain the variation in yield of second and third crops, as well as the insignificance of the contribution of the third crop (maize) yield to the total annual crop production.

5.5 Cropping Intensity

5.5.1 Definition

Much of the irrigated area in countries such as Nepal lies within the humid and sub-humid tropics, therefore the production of three crops per year is often possible. The intensity of the existing SMIS cropping system was measured by calculating the seasonal and annual Cropping Intensity Ratios (CIR) described in Section 4.4.1 for all 68 farms in the four branch areas studied. The annual CIR accounts for the number of crops grown through the year and the percentage of cultivable land within the irrigation system boundaries on which each of the crops is grown during a particular season.

5.5.2 Data Used

i) Tables 5.22 - 5.25 in Section 5.3.2 include the seasonal CIR for each of the second and third crop seasons for each of the 68 farms monitored in the four intensive study areas.

ii) The summary CIR data is tabulated in Table 5.40.

iii) Background data on land holding size, tenancy, and the proportions of fallow farms is provided in Tables 5.41 and 5.42 for interpretive purposes.

iv) Cropping intensity data from the adjacent Bhairawa Lumbini Groundwater Project (BLGWP) irrigation system and average cropping intensities for the region are provided for comparison in Table 5.43(a) and (b), and in Table 5.44.

Table 5.40 Summary of Cropping Intensity Ratios in the SMIS during the 1988-89 Crop Year

Season	Seasonal CIR of Cultivable Farm Areas Cropped in the Branch Canal Areas			
	W. Sidd. (head)	A-M #10 (middle)	A-M "7b" (middle)	Khopiya (tail)
Monsoon (crop 1)	1.0	1.0	1.0	1.0
Winter (crop 2)	0.94	0.98	1.0	0.49
Spring (crop 3)	0.47	0.31	0.24	0
Annual Cropping Intensity Ratio	2.41	2.29	2.24	1.49

Table 5.41 Average landholding size and proportion of owner and tenant farmers in the branch canal areas

Branch Canal Areas	Average Landholding Size (ha)	Landowners (%)	Tenants (%)
W. Sidd. (head)	0.38	81	19
A-M #10 (middle)	0.64	83	17
A-M "7b" (middle)	0.94	60	40
Khopiya (tail)	1.85	89	11

Table 5.42 Proportions of Farms which were completely fallow during a crop season

Season	Proportion of Farms Fallow in each Branch Canal Area (%)			
	W. Sidd. (head)	A-M #10 (middle)	A-M "7b" (middle)	Khopiya (tail)
Monsoon (Crop 1)	0	0	0	0
Winter (Crop 2)	3	0	0	0
Spring (Crop 3)	13	39	40	100

Table 5.43(a) Cropping intensities, Bhairawa Lumbini Groundwater Project, Present Conditions (Tahal, 1988)

Season	Percent of Cultivable Area Cropped	
	Lowlands	Midlands/Uplands
Monsoon	85	90
Dry	5	55
Annual Cropping Ratio[1]	0.90	1.45

Note:

[1] Overall Cropping Intensity = 1.20

Table 5.43(b) Cropping intensities, BLGWP Proposed Target Levels (Tahal, 1988)

Season	Percent of Cultivable Area Cropped		
	Lowlands	Midlands	Uplands
Monsoon	90	90	90
Winter	0	85	90
Spring	50	50	35
Annual Cropping Ratio	1.40	1.85	2.15

Table 5.44 Cropping intensities, Western Development Region (CIWEC, 1989)

Number of Crops	Percent of Cultivable Area Cropped		
	Rain-fed	Monsoon Irrigation	Year-Round Irrigation
1	100	100	100
2	22	98	87
3	0	0	3
Annual Cropping Ratio	1.22	1.98	1.90

5.5.3 Analysis

Given a maximum possible cropping intensity ratio of 3.0 (which would indicate that three crops were grown on all of the cultivable land during the year) the cropping intensities in the head and middle areas of the irrigation system command area are high, with West Siddhanagar (head) farmers achieving an annual cropping intensity ratio (CIR) of 2.41 and Anandavan Madhuban (middle) #10 branch, 2.29 and "7 bigha" branch achieving an CIR of 2.24. The cropping intensity in the Khopiya branch area (tail) is much lower, with a CIR of 1.49.

Comparison of the achieved SMIS CIR values with the target CIR values for the BLGWP shows that cropping intensity in the SMIS is considerably higher (refer to Figure 5.40 and Table 5.43). Even the low CIR of 1.49 for the Khopiya area is higher than the BLGWP target CIR of 1.40 for similar lowland (poorly drained) areas. SMIS CIR values for the head and middle areas (ranging from 2.24 to 2.41) also compare favourably with average regional CIR values found in Table 5.44 (ranging from 1.90 to 1.98 for irrigated areas).

A higher proportion of farmers in the Anandavan-Madhuban (A-M) "7 bigha" area are tenants than in A-M #10 (refer to Table 5.41), resulting in a somewhat lower CIR. Tenant farmers sometimes have their own small plot of land nearby on which they concentrate their efforts. Tenants may also have less incentive to cultivate second and third crops which are less profitable (than the first rice crop), since they typically receive only 50 percent of the proceeds.

The lower CIR in Khopiya is due to several factors:

i) Much of the cultivated area is low lying and poorly drained. Consequently, farmers cannot harvest the first (rice) crop or till the fields for a second crop until one to two months after rice maturation, thus virtually eliminating the possibility of cultivating a third crop during the crop year.

ii) Land holdings are larger and available farm labour is relatively scarce, thus the incentive for or possibility of planting second or third crops is greatly reduced.

iii) Available water supply at the SMIS headworks is so low during the spring (dry) season that most if not all of it is lost to conveyance losses over the length of the canal. Farmers (especially in the tail areas) have learned that it is not worthwhile to attempt to cultivate a third crop with such an inadequate water supply.

iv) In the spring season, most tail area farmers graze cattle on their land, thus fencing or a change in this agricultural practice would be required for a farmer to cultivate a third crop there.

Data analysis indicated a high degree of correlation between individual farm and the average CIR values, which indicates uniformity or equity in the proportion of each farmer's land which is cropped over the crop year within a particular branch area. Such a correlation also indicates that farmers are confident of receiving an equitable proportion of the available water supply for a given season.

Since water allocation is based on land area through the first and second crop seasons, variation in land holding size does not influence cropping intensities. However, during the third crop season water is allocated in equal proportions to each farmer regardless of land holding size in order to give all farmers an opportunity to cultivate a small area of their land with the limited water available. The data further indicates a direct correlation between cropping intensities and average land holding size. For example, smaller land holdings in West Siddhanagar (0.38 Ha/farm) exhibit a much higher average cropping intensity ratio of 0.47 during the third crop season than in A-M "7 bigha" with its larger land holdings (0.94 Ha/farm) and an average cropping intensity ratio of 0.24.

The proportion of farms within each area which were left completely fallow during the third crop season has a significant influence on the CIR values for the various branch areas during that period and are listed in Table 5.42. The number of farms lying fallow during the third season steadily increases from head to tail of the irrigation system. Such a spatial variation in fallow farms can be attributed to factors already mentioned - water availability, incentive, and in the case of some tail-end areas, poor drainage.

CHAPTER 6

CONCLUSIONS

6.1 Water Use Efficiency

Conveyance efficiency of the main canal is very poor during the water scarce periods of the dry season. Consequently the availability of water to the branch canal systems (maujas) is severely reduced in the dry season, especially for the middle and tail areas of the SMIS. Extrapolation of seepage test results indicate that conveyance efficiency should be much higher when the main canal is carrying the much higher flows for which it is designed, since the wetted perimeter increases only moderately for a corresponding very large increase in flow.

Distribution efficiency varies depending on the size of the branch canal area distribution system and the distance over which water must be conveyed from the main canal to the fields. Overall, the distribution efficiencies in the SMIS are quite good. During periods of water scarcity, farmers optimize the distribution efficiency by rotating water deliveries from branch to branch.

Irrigation system efficiencies cannot be readily compared due to a lack of quantifying contextual information together with reported efficiencies in literature. Nevertheless, the range of efficiencies observed for the SMIS appear to be typical of surface water irrigation systems with unlined earthen canal water distribution systems which employ basin irrigation.

Water distribution, and particularly main canal conveyance efficiencies, must be improved during the water scarce period of the dry season if crop water requirements are to be adequately met and if third crop seasonal cropping intensity is to be increased.

6.2 Water Allocation and Equity

SMIS managers are very proficient in maintaining the stated water allocation principles, and a high degree of equity is achieved in water allocation. However, if the water allocation (or entitlement) to branches (maujas), particularly in those areas farther from the head, is considered against actual water deliveries to them during the dry season, conveyance losses produce a steadily decreasing level of equity in delivery moving towards the tail of the SMIS.

Intensive water management in the SMIS has achieved considerable success in apportioning some amount of dry season water supply to each farmer who wants it in a reliably scheduled manner. But SMIS managers are constrained in the level of dry season water delivery equity that they can achieve by the inefficiency of the existing water distribution system.

6.3 Water Adequacy

The water supply was adequate for planting irrigated crops on virtually all of the cultivated land in the head and middle areas of the SMIS during crop season 2. Therefore, the area cultivated to irrigated crops such as wheat (versus non-irrigated crops such adahar) could be increased in these areas (but the cropping intensity ratio itself cannot be increased).

Tail end farmers do not appear to enjoy the same potential for expanding their irrigated or cropped area during crop season 2. However, the constraints on tail end expansion may be due to poor drainage and cultural practices for instance, and not simply an inadequate water supply.

Timeliness of irrigation deliveries appears to be very good during crop season 2 when water is available on demand. The excellent yields reported for wheat rendered further analysis of crop stress and timeliness unnecessary.

Planting a third crop is a risky endeavour for SMIS farmers. The river water supply is very low at the beginning of that season (April/May), rainfall in unreliable, and the hot, dry climatic conditions produce very high crop water requirements.

Timeliness of water deliveries also suffers during the beginning of the third crop season when a strict rotation schedule is followed. Because the schedule takes a long time to complete (three to four weeks), the critical growth stages of some farmers' crops do not match the timing of their irrigation deliveries and crop stress results.

6.4 Crop Production

Crop production performance for the principal crops of rice (crop season 1) and wheat (crop season 2) is very good - meeting or exceeding current and target local, regional and national levels.

Performance of crop production of secondary crops such as lentils and maize in seasons 2 and 3 is not as high, and considerable room for improvement should be noted in this area. However, current levels of water supply, essentially during the spring (crop season 3), are inadequate and thus increased crop production during this period is not feasible until measures can be implemented to improve water adequacy.

Yields vary widely between individual farms. While some yield variation is due to physical differences such as soil fertility, there remains room for significant yield improvement on the part of some farmers if they were to adopt improved agricultural practices and inputs.

6.5 Cropping Intensity

Cropping intensity in the head and middle areas of the SMIS is very high, with the maximum level of 100% being achieved for the first crop and very nearly achieved for the second crop. Lower cropping intensity in these areas for the third crop is due largely to an inadequate water supply in the late spring (particularly during April and May).

Cropping intensity in the tail area of the SMIS is moderate. While maximum intensity is achieved for the first crop, a much lower intensity level is achieved for the second crop season, and the entire area is fallow in the spring. The potential for expanding the cropping intensity in the tail is constrained by poorly drained soil conditions, a shortage of farm labour, inadequate water supply for a third crop, and current agricultural practices.

The performance of the SMIS in terms of cropping intensity is very good since achieved levels are at or near the maximum attainable under the present conditions, and CIR values for the SMIS meet or (in most cases) significantly exceed local and regional CIR values. The most significant constraint to increasing the annual cropping intensity ratios throughout the

SMIS is an inadequate water supply during the third crop season (March through May).

CHAPTER 7

RECOMMENDATIONS

7.1 Water Use Efficiency

There are a number of options available to improve irrigation system (conveyance and distribution) efficiency of the SMIS:

i) The main canal may be lined with an impervious lining such as concrete, or a membrane covered by gravel and rip rap. However, there are serious limitations to the effectiveness of this solution;

- the cost of lining is very high and the necessary outside assistance would be likely to exclude farmers from the control of such a project which would could lead to its failure,
- the available water supply in the Tinau River is very low, farmers have a difficult time diverting

what is presently available, therefore careful consideration would be required to determine whether the available supply could irrigate a significantly larger area than at present in order to produce a favourable cost-benefit ratio,

- large deposits of gravel (sediments) are washed into the canal system every year and would seriously reduce the effectiveness of the lining.

ii) A smaller channel section constructed in the bed of the existing main canal to carry the lower dry season flows could be effective in reducing conveyance losses, but is subject to the following constraints (refer to Figure 7.1):

- the heavy annual monsoon sedimentation would fill the sub-channel with hard packed gravel,
- substantial seepage losses would still be incurred by the ponding required to raise the water level to sufficient head in the main canal with which to pass it into the branch canal inlet,
- the sub-channel lining could be easily damaged during the annual de-silting maintenance work (since the deposited sediments are very hard-packed and difficult to remove).

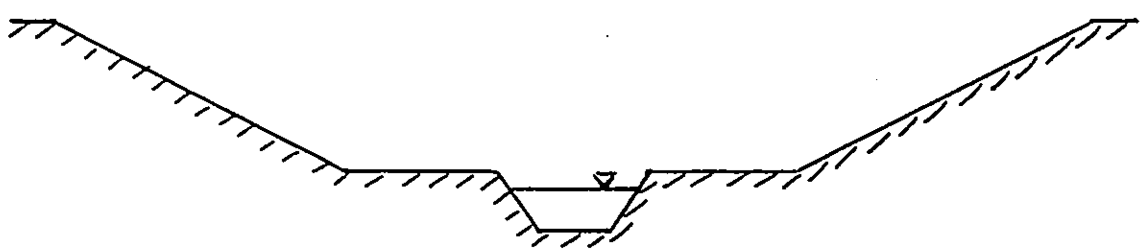


Figure 7.1 A smaller channel section in the bed of the SMIS main canal

iii) A more effective alternative to (ii) may be to construct a smaller lined canal (or a pipeline) with a capacity of 0.50-1.0 m^3/s along one side of the existing main canal to carry lower dry season flows (refer to Figure 7.2). Water deliveries could be spilled from this sub-main into the existing branch canals. Several aqueducts would be required to deliver water to branches on the opposite side of the main canal. The Taraprasad bhod regulator would require some modifications to facilitate diversion of water into the smaller sub-main and to block off the existing main canal. The main canal would continue to be used to convey high monsoon flows. (Note that bank stabilization measures are nevertheless needed to improve the main canal.)

iv) Increasing the use of proportional division structures could lead to a reduction in the total length of branch canals in the systems. (In many cases, branch canals exist side by side, serving farmers in adjoining areas who prefer to control their own water supply all the way from the main canal). SMIS farmers are very adept at design and construction of proportioning structures (refer to Figure 7.3). The confidence of farmers in adopting division structures to allocate water could be fostered by construction of water-tight, lockable gates

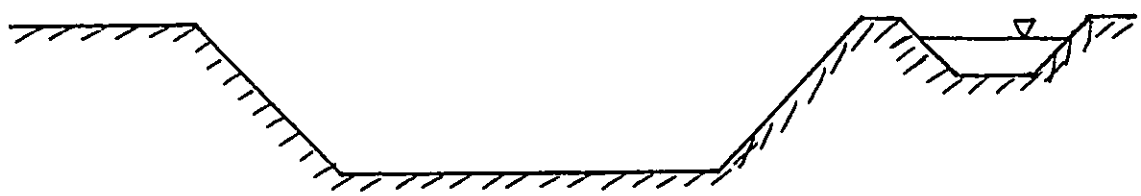


Figure 7.2 A smaller (dry season) canal in parallel with the existing SMIS main canal

Figure 7.3 A proportional structure (weir) designed and constructed by farmers

on these structures to ensure that the present system of allocation is maintained.

v) If the BLGWP command area were to be further expanded north into the SMIS (say to the Manigram - Nyamil, #10 Road), groundwater could supply winter and spring crop water requirements in the tail and lower-middle areas of the SMIS (refer to Figure 3.1, back pocket). Available surface water supplies could then be used more efficiently in the head and upper-middle areas where conveyance distances, and thus losses, could be greatly reduced. (Note that works to improve soil drainage in the tail end areas are also necessary if cropping intensity is to be increased there.)

vi) Farmers have already proposed the construction of more permanent division structures (similar to the Taraprasad bhod weir) on the main canal to divert water to the branch canals. Construction of such structures with water-tight gates would eliminate leakage from the main canal and prevent water stealing, thus improving conveyance efficiency and the equity of water allocation.

Irrigation system efficiencies could be more readily compared between systems if they were reported on a per unit canal length basis, or at least with contextual background information to allow the formulation of such comparative data. Further research is needed to determine whether canal conveyance and distribution loss rates are constant or proportional to the length of the canal in question. By measuring flows at several points along a uniform length of canal and plotting the flows measured at each station. A "best fit" linear relationship between flow and distance would indicate a constant loss rate, while a curve relationship would indicate a proportional loss rate.

Further research to definitively assess field application efficiency could also be useful to irrigation system designers, planners and managers. It is apparent from field delivery measurements that there is considerable variation in the depths of application between farmers which may be reduced by improved control structures. Application efficiency could also be improved if those farmers who irrigate from basin to basin could be encouraged to further develop their farm ditch networks to allow all water deliveries to be made directly from the ditch to the basin.

7.2 Water Allocation and Equity

Further development and improvement of division structures in the main canal at the branch canal inlets would permit water measurement at those points. Consequently, more equitable deliveries of water (on a volumetric basis) could be made to individual maujas which would account for conveyance losses. Farmers have already expressed a desire to continue developing and constructing such control structures. It is uncertain however, whether farmers would be willing to alter their dry season allocation principles to account for conveyance losses. It is possible that farmers are satisfied with the operation of the present principles and may in fact feel that changes to it would give rise to perceived inequity. Careful sociological study should be undertaken to accurately assess farmers attitudes. Farmers have shown a willingness to change and adopt new ideas in the past, but the process of change must be slow and farmers must be convinced of the value of what is proposed.

Reduction of conveyance losses (refer Section 5.1) will improve water delivery equity by more closely matching deliveries with allocation, without making any changes to the water allocation principles.

Branch areas (maujas) above the Taraprasad bhod regulator are presently taking more than their allocated share of water. Government legislation giving legal empowerment to the SMIS Committee for water management and control of those areas will greatly enhance the effectiveness of the organization in maintaining its principles of operation.

7.3 Water Adequacy

The improved efficiency of the water conveyance and distribution system would enable larger quantities of water to be delivered more frequently (and with increased timeliness) than at present during the water scarce months of the dry season.

Seasonal water application data collected in the course of this research for wheat farmers should be used in the design of water duties for similar irrigation systems proposed to be developed in the Terai. Real measured data should be used to qualify standard design criteria which may be somewhat simplistic and often underestimate the required water supply.

Further research should be undertaken to quantitatively assess the effects of irrigation frequency and the timeliness of deliveries to meet critical growth periods and thus reduce crop stress. Comparison of these parameters should be made with crop yields.

7.4 Crop Production

Most farmers are not particularly concerned about third crop production, other than for their own use, or for some additional cash income in a good year. Improved market availability may increase incentives to farmers to increase production.

Measures to improve water adequacy for the spring season (refer to Section 5.3) would permit and encourage increased crop production for that period.

Cropping schedules may be altered to make more effective use of the available water supply.

Improved agricultural practices such as improved seeding methods, should continue to be encouraged. However, reliance on high yielding varieties (HYV's) of crops which require very high fertilizer inputs may produce artificially high yields that would be very susceptible to uncontrollable factors such as the availability of such inputs over the long term.

Assessing the net incomes of farms may be a more accurate and useful measure of crop production performance.

7.5 Cropping Intensity

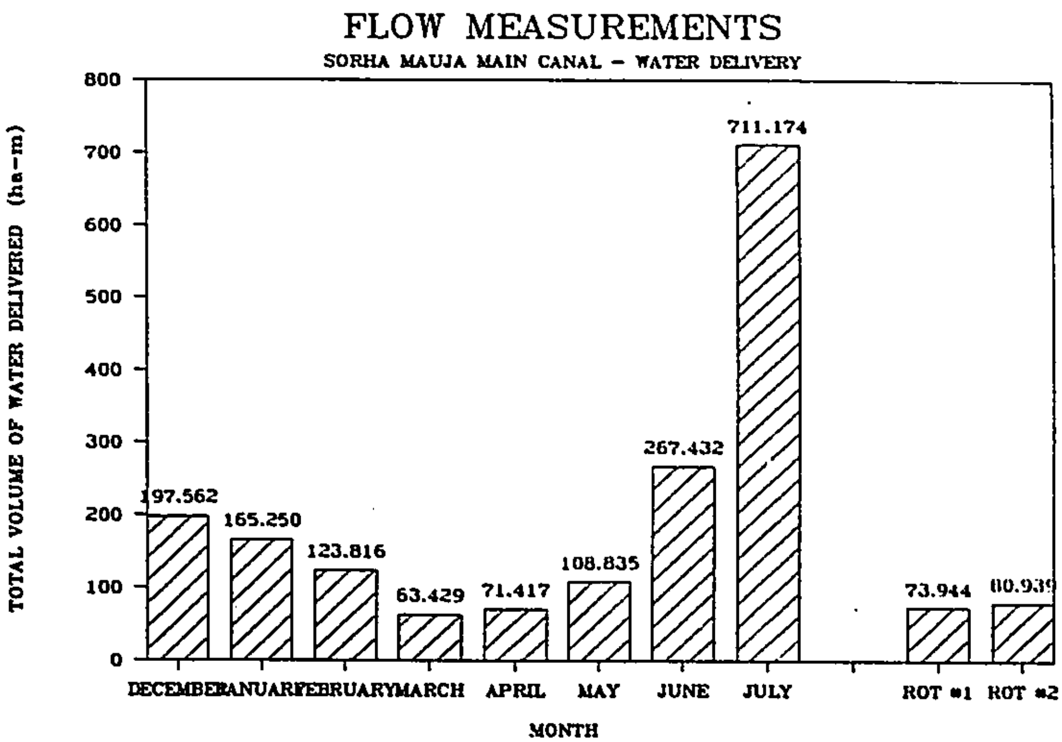
Second crop intensity in the tail area could be significantly increased by:

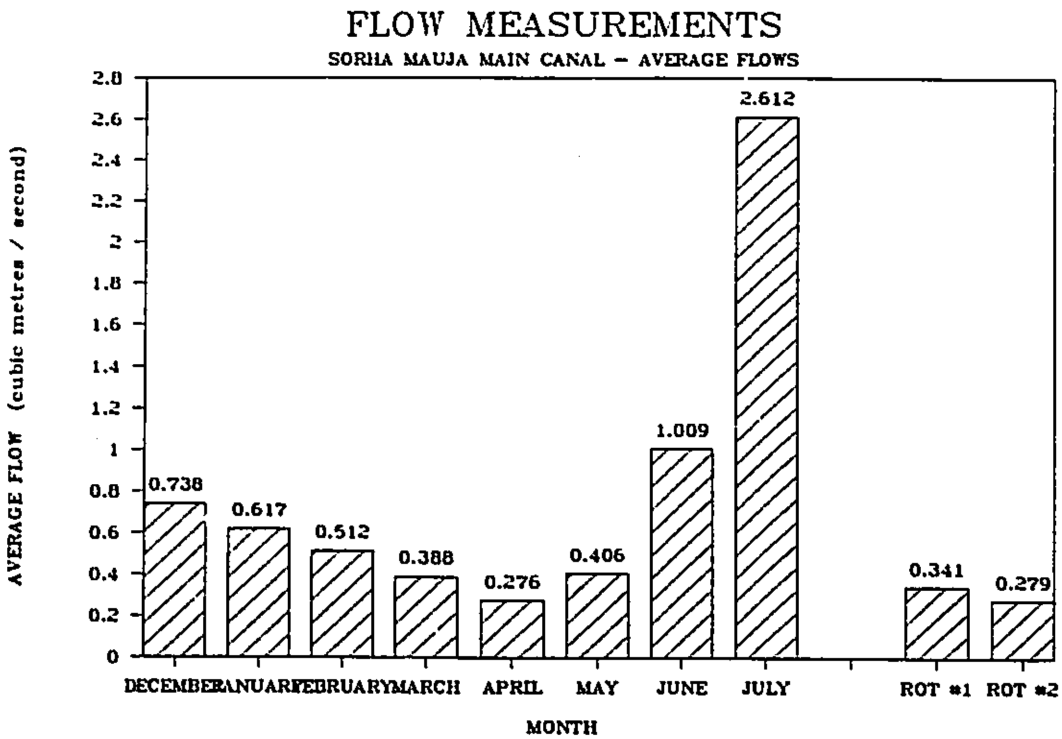
- encouraging the development of a drainage system which would allow earlier harvest of rice and planting of the second crop, which in turn would allow farmers to take advantage of the adequate water supply available in winter.
- introducing measures to improve the market for increased crop production and to encourage more farm labourers to work in the area.

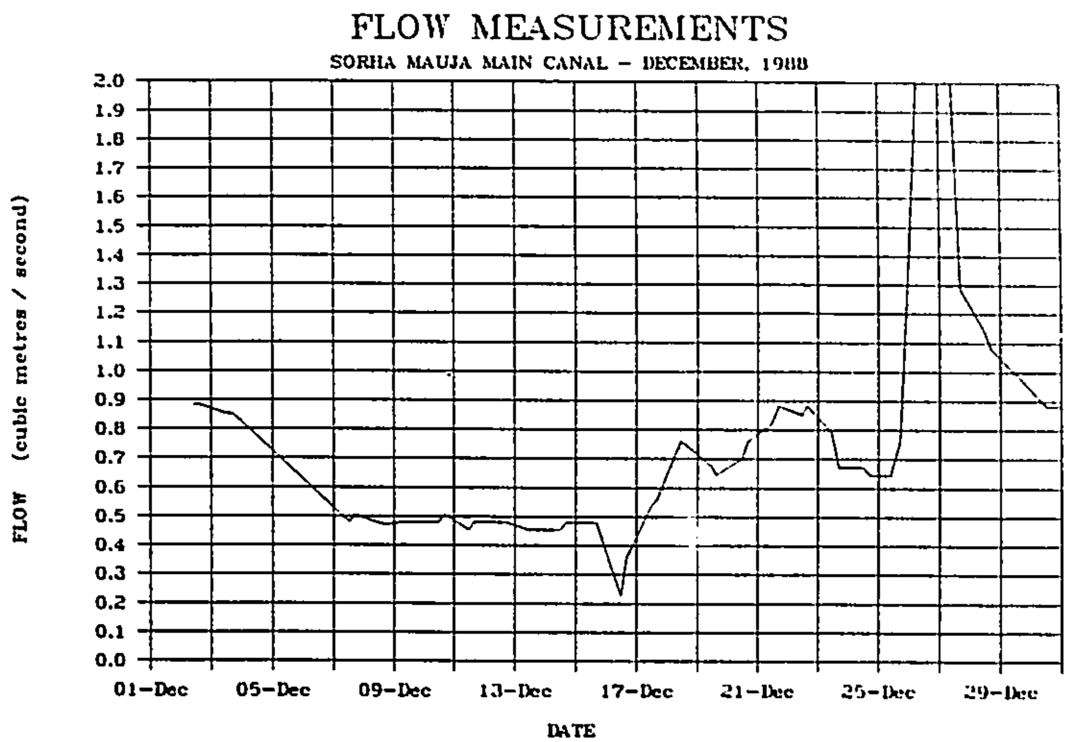
Cropping intensity in the third season could be significantly increased in all areas of the SMIS if the available water supply was somehow increased. One alternative may be to expand the development of groundwater supplies north into the tail and lower middle areas, leaving available surface water for use in the head and upper middle areas during the spring when surface water from the Tinau river is in very limited supply. If this alternative is followed, great care must be taken to ensure that the surface water supply infrastructure and most importantly the management system and authority is maintained and enhanced. When the BLGWP was first initiated, serious damage was done to the existing system of farmer management and self-sufficiency in the project area. Current efforts to remedy this problem by increasing farmers involvement and responsibility in the operation and maintenance of the system are proving difficult and costly. Other alternatives, such as increasing canal conveyance efficiency (previously mentioned) could also provide for some marginal improvement in cropping intensity if farmers developed confidence in the resultant increased water supply.

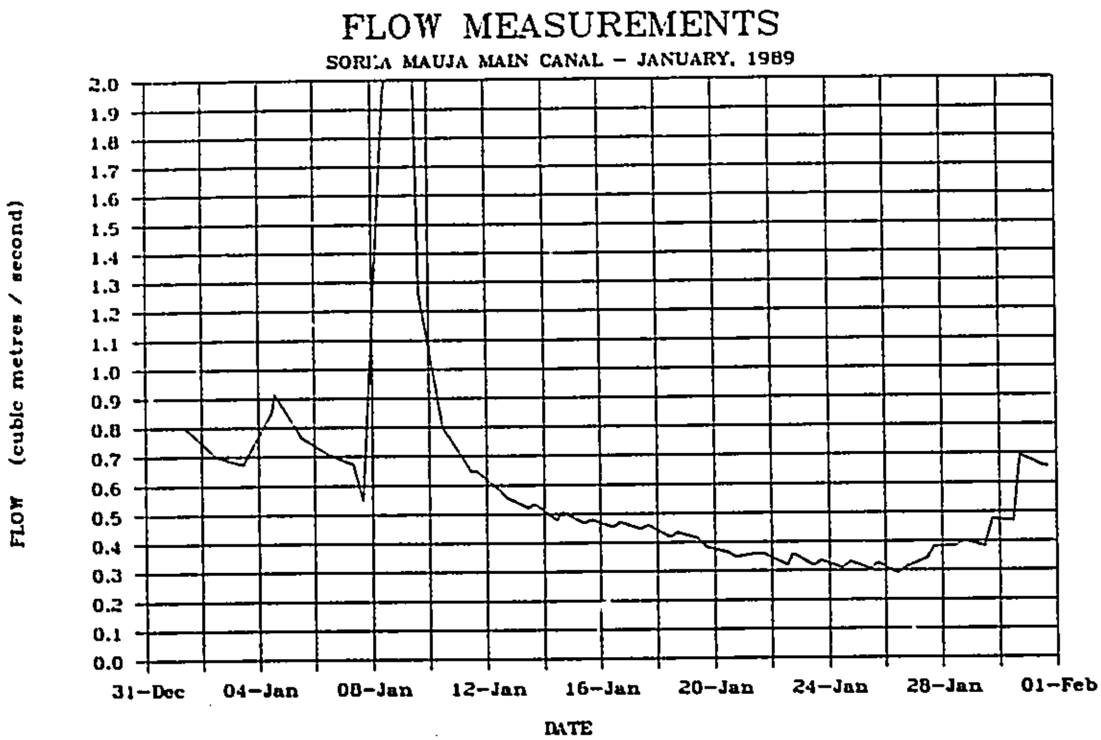
APPENDIX A

FLOW DATA

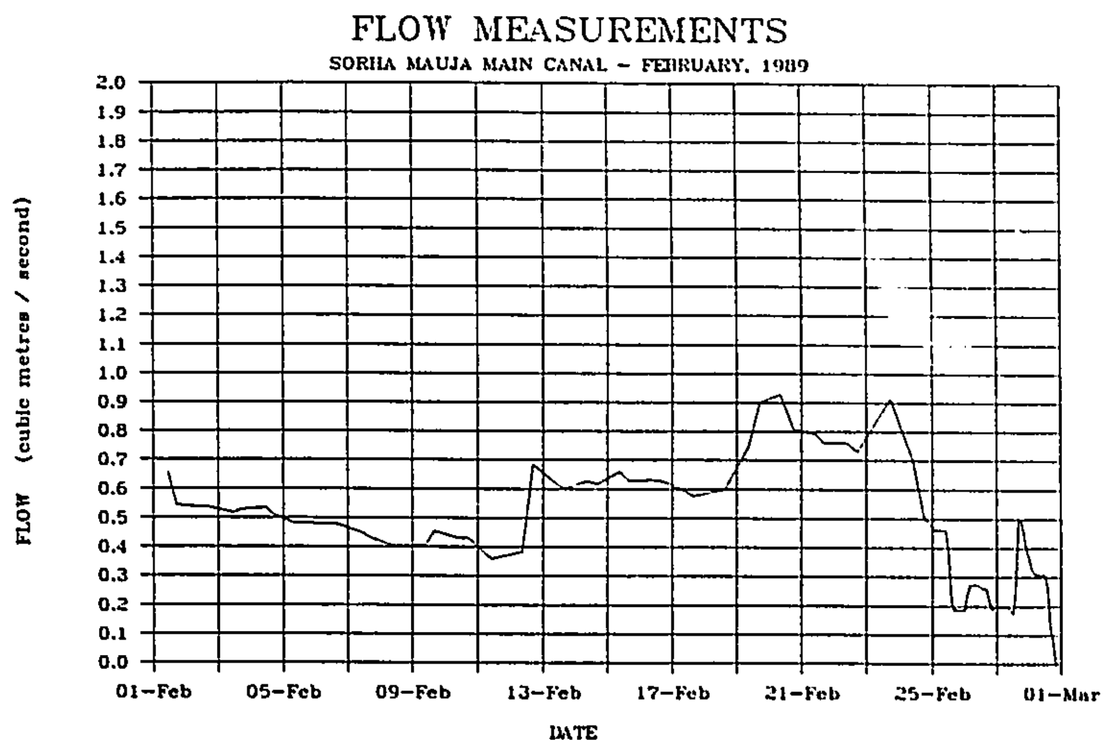

FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL - WATER DELIVERY
TOTAL VOLUME OF WATER DELIVERED (ha-m)
800
700
600
500
400
300
200
100
0
197.562
165.250
123.816
63.429
71.417
108.835
267.432
711.174
73.944
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
ROT #1
ROT #2
MONTH

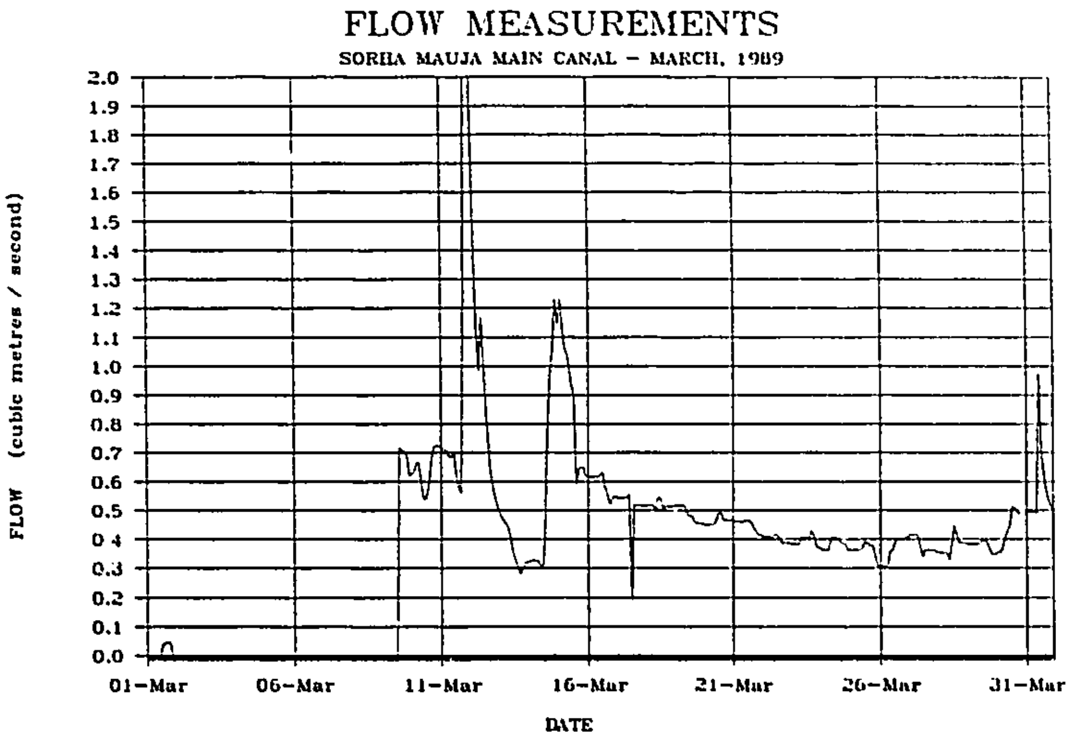

FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL – AVERAGE FLOWS
AVERAGE FLOW (cubic metres / second)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.738
0.617
0.512
0.388
0.276
0.406
1.009
2.612
0.341
0.279
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
ROT #1
ROT #2
MONTH

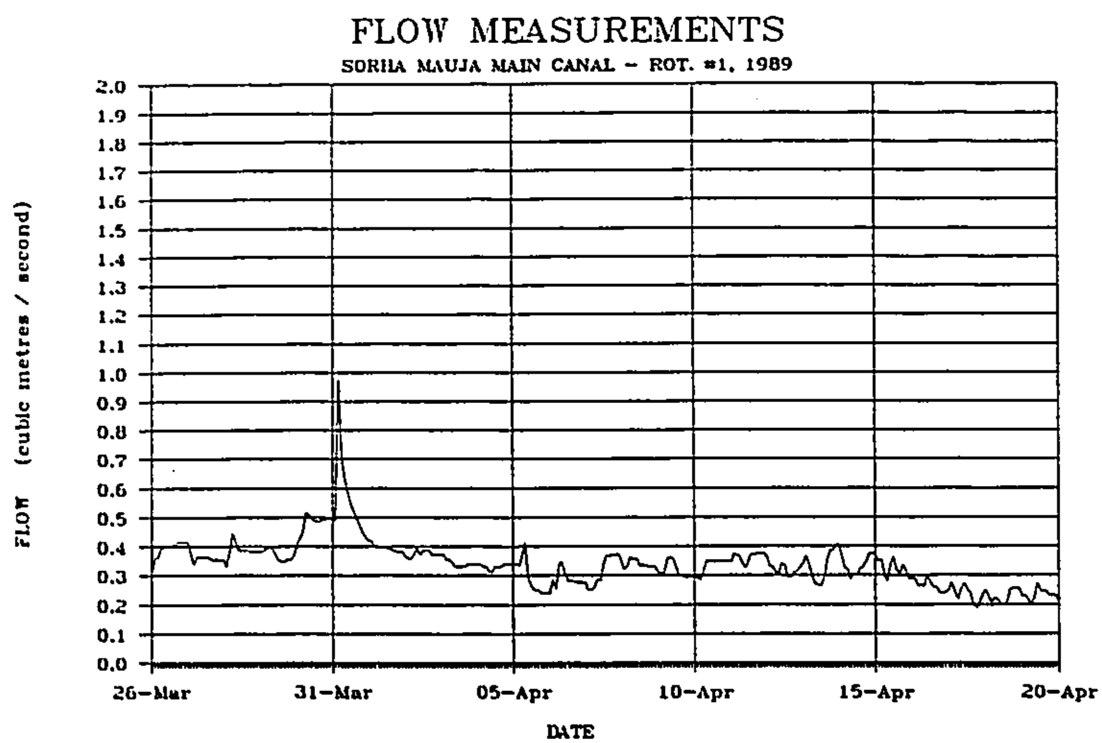

FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL – DECEMBER, 1988
FLOW (cubic metres / second)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
01–Dec
05–Dec
09–Dec
13–Dec
17–Dec
21–Dec
25–Dec
29–Dec
DATE

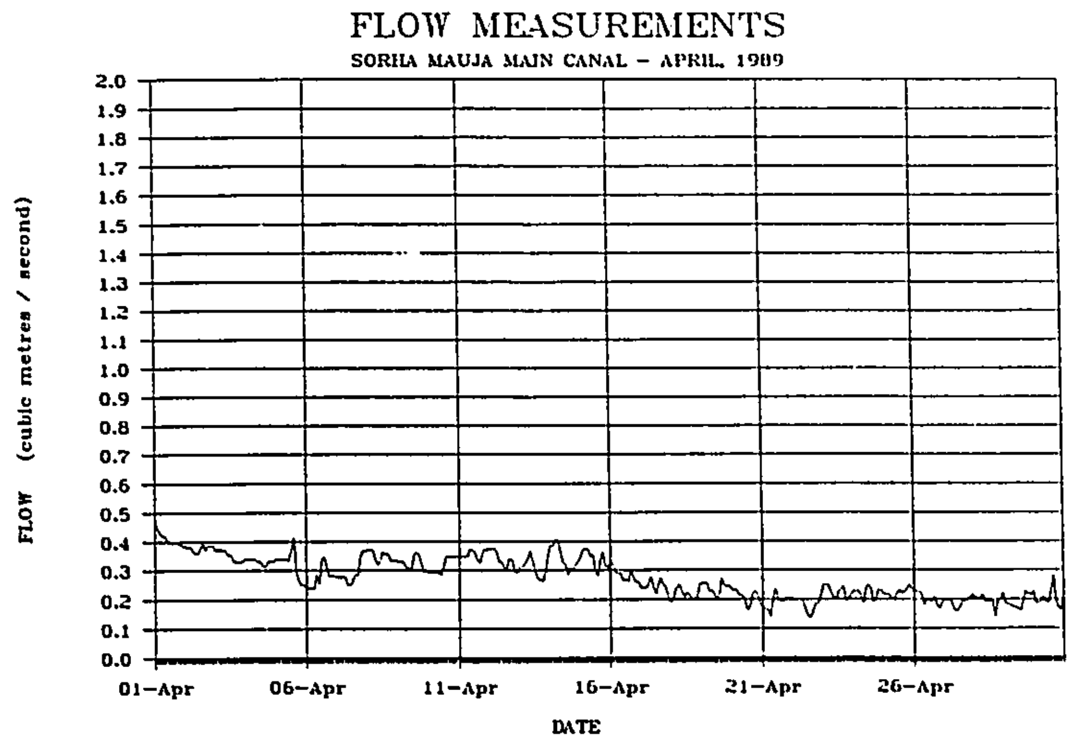


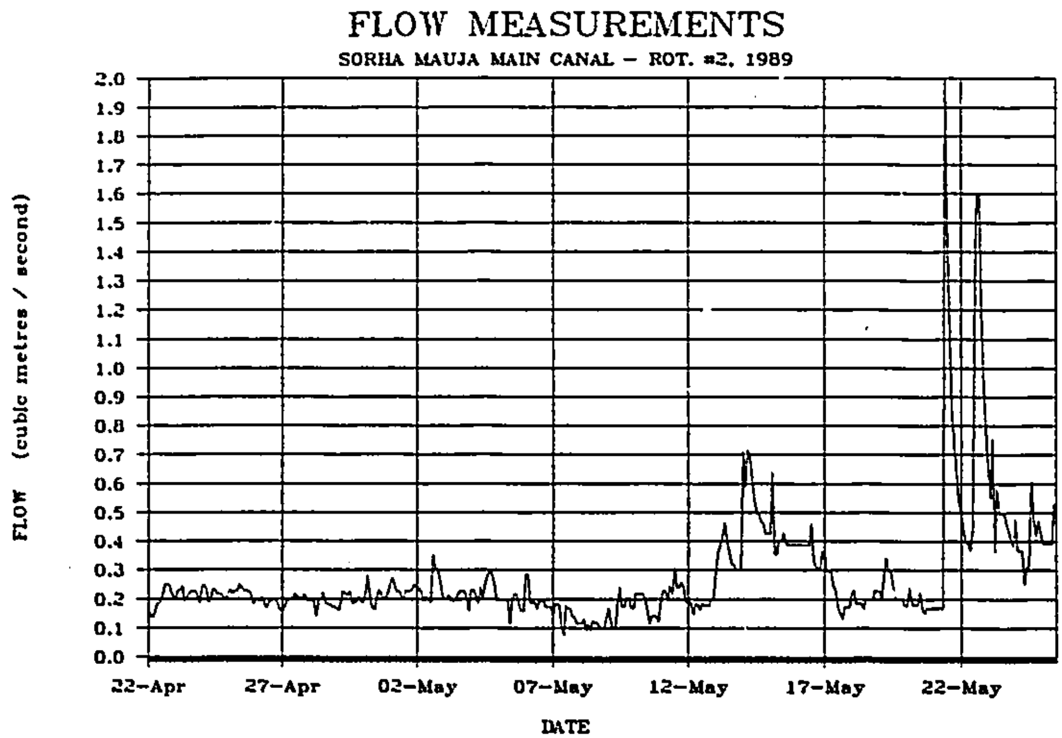
FLOW MEASUREMENTS
SORILA MAUJA MAIN CANAL – JANUARY, 1989
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
FLOW (cubic metres / second)
31-Dec
04-Jan
08-Jan
12-Jan
16-Jan
20-Jan
24-Jan
28-Jan
01-Feb
DATE

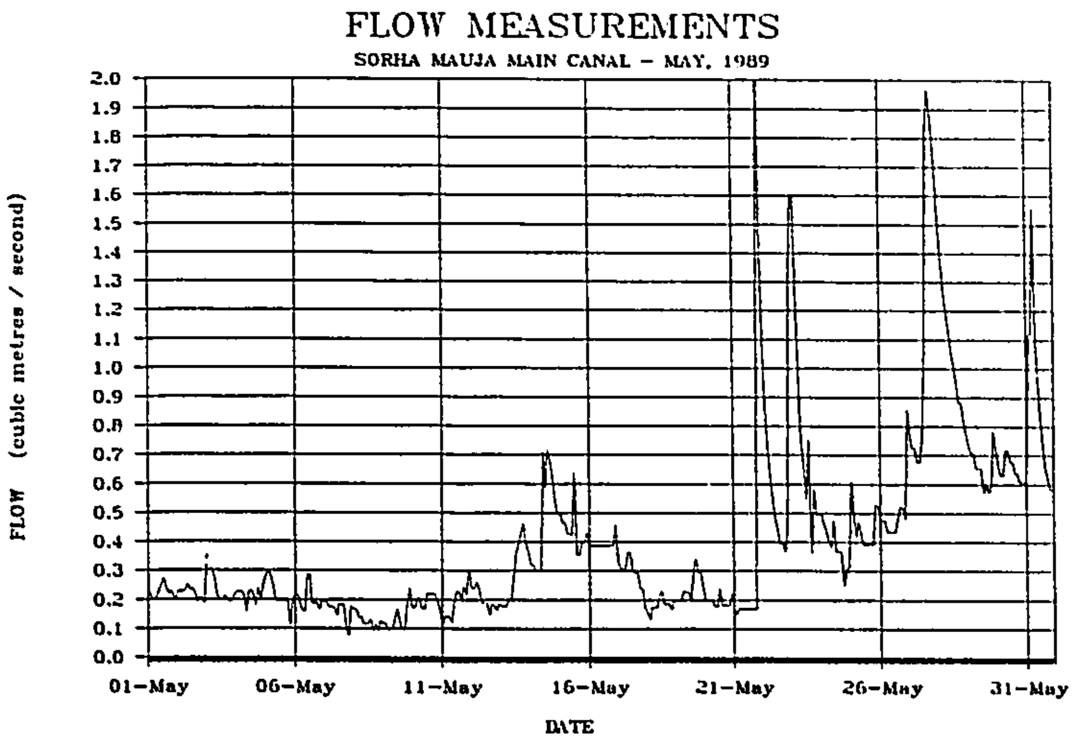

FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL - FEBRUARY, 1989
FLOW (cubic metres / second)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
01-Feb
05-Feb
09-Feb
13-Feb
17-Feb
21-Feb
25-Feb
01-Mar
DATE


FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL – MARCH, 1989
FLOW (cubic metres / second)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
01–Mar
06–Mar
11–Mar
16–Mar
21–Mar
26–Mar
31–Mar
DATE

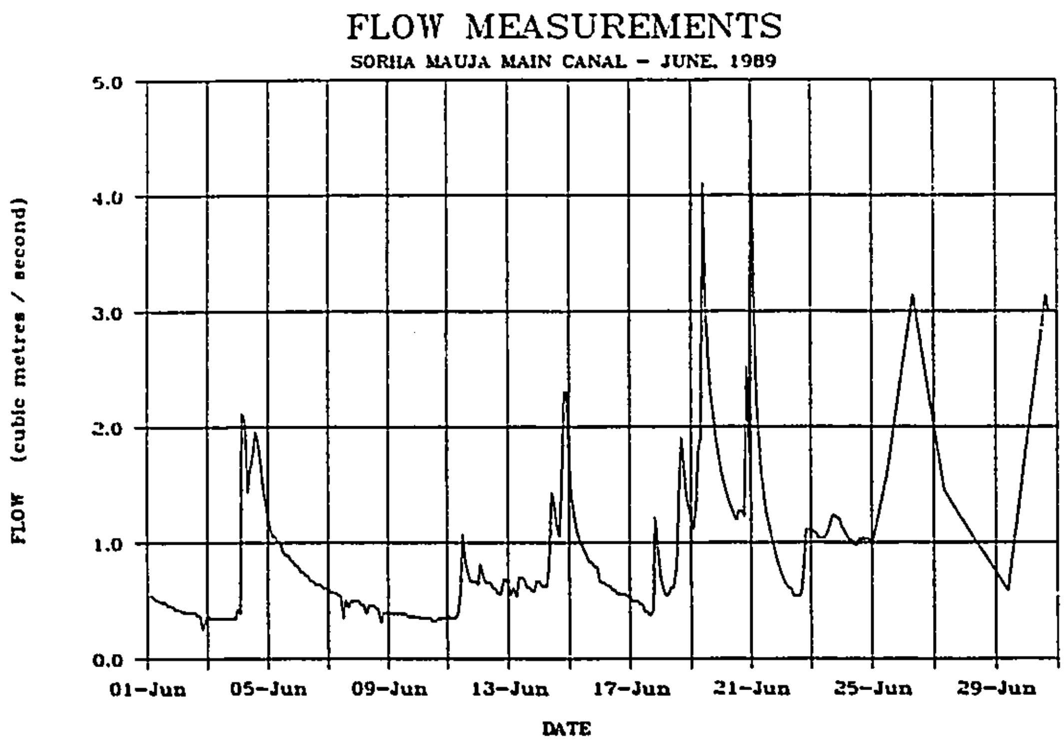

FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL - ROT. #1, 1989
FLOW (cubic metres / second)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
26-Mar
31-Mar
05-Apr
10-Apr
15-Apr
20-Apr
DATE


FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL – APRIL, 1989
FLOW (cubic metres / second)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
01–Apr
06–Apr
11–Apr
16–Apr
21–Apr
26–Apr
DATE

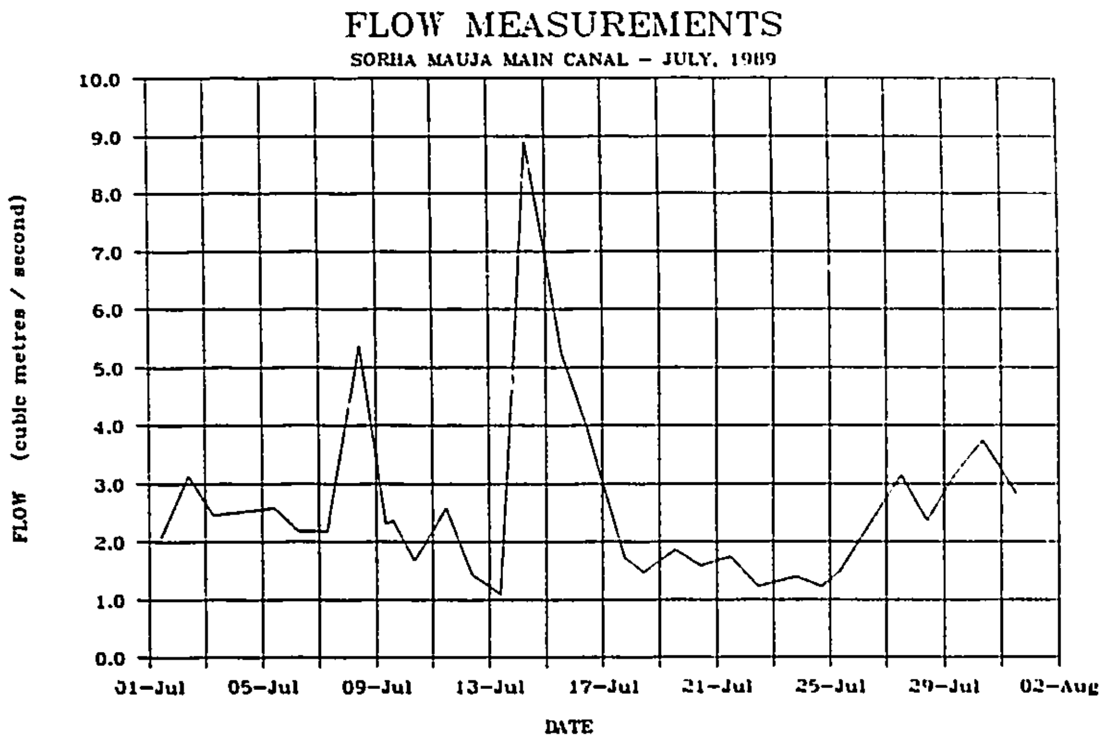

FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL - ROT. #2, 1989
FLOW (cubic metres / second)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
22-Apr
27-Apr
02-May
07-May
12-May
17-May
22-May
DATE

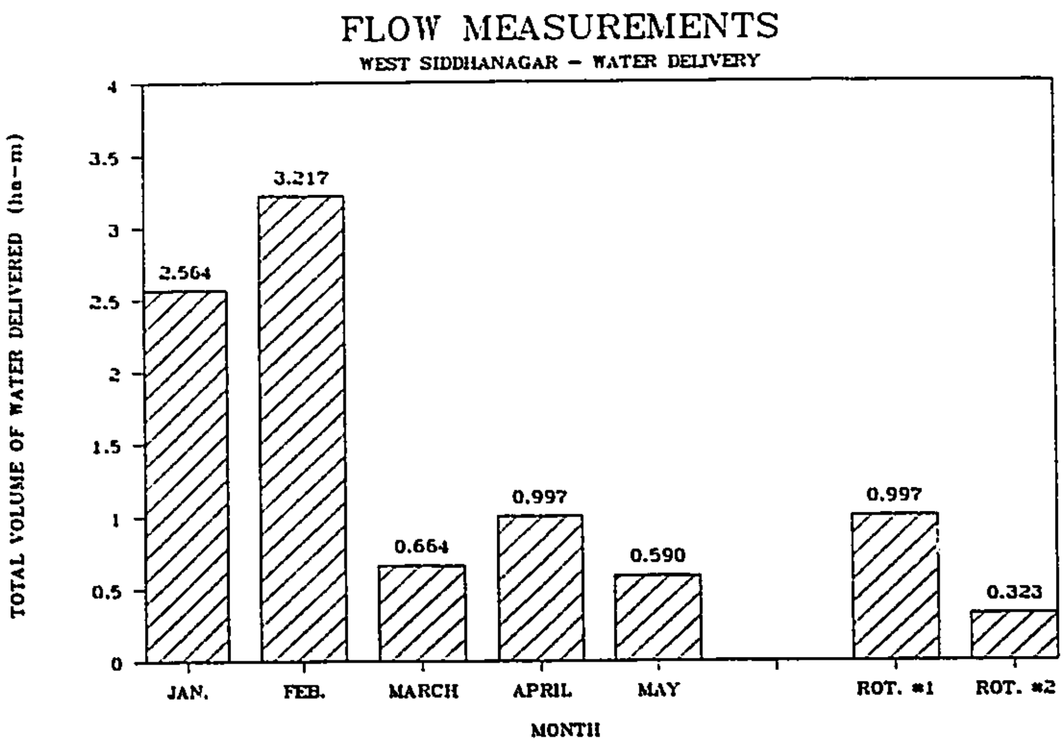


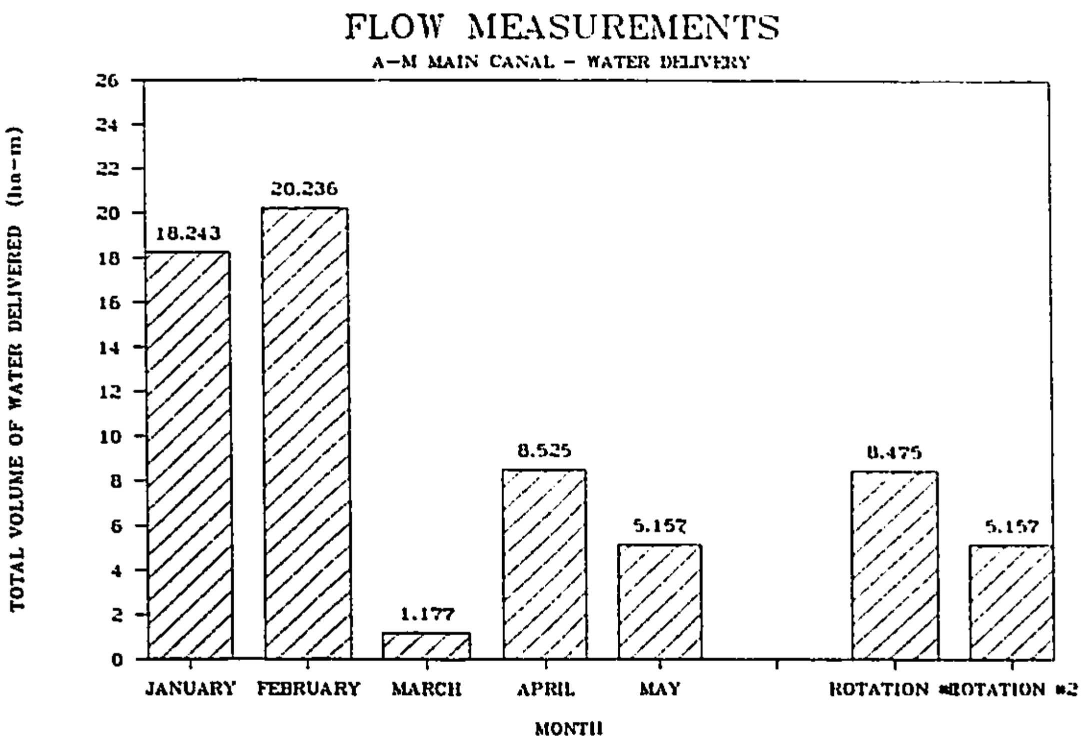
FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL – MAY, 1989
FLOW (cubic metres / second)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
01–May
06–May
11–May
16–May
21–May
26–May
31–May
DATE

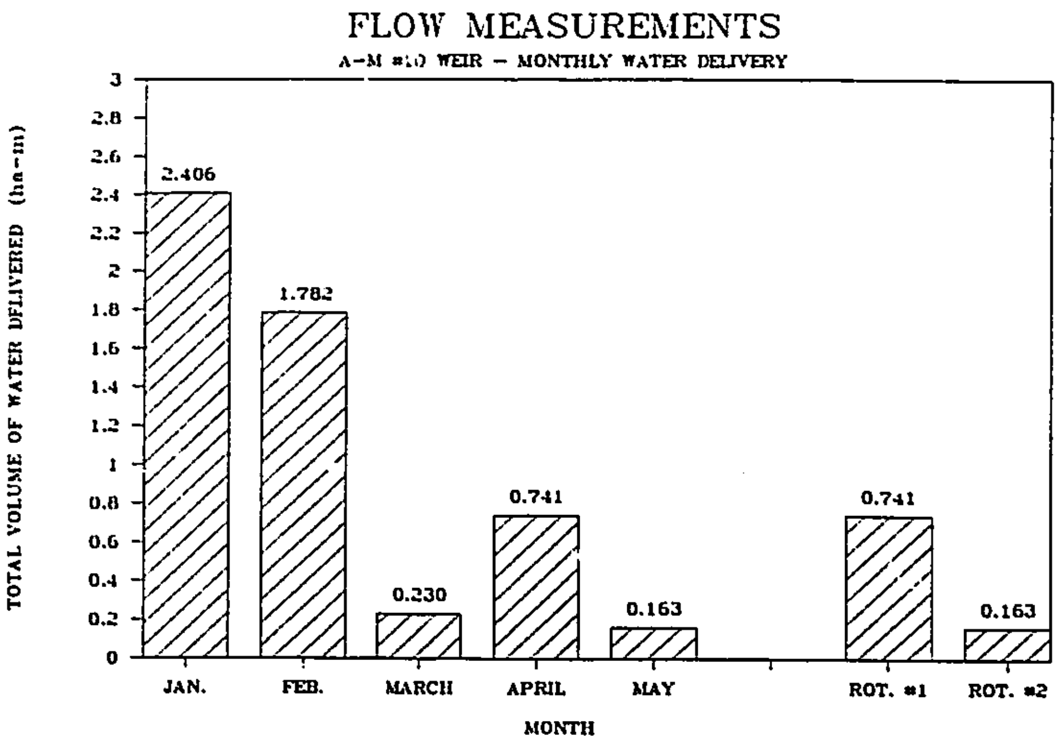


FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL - JUNE, 1989
FLOW (cubic metres / second)
0.0
1.0
2.0
3.0
4.0
5.0
01-Jun
05-Jun
09-Jun
13-Jun
17-Jun
21-Jun
25-Jun
29-Jun
DATE

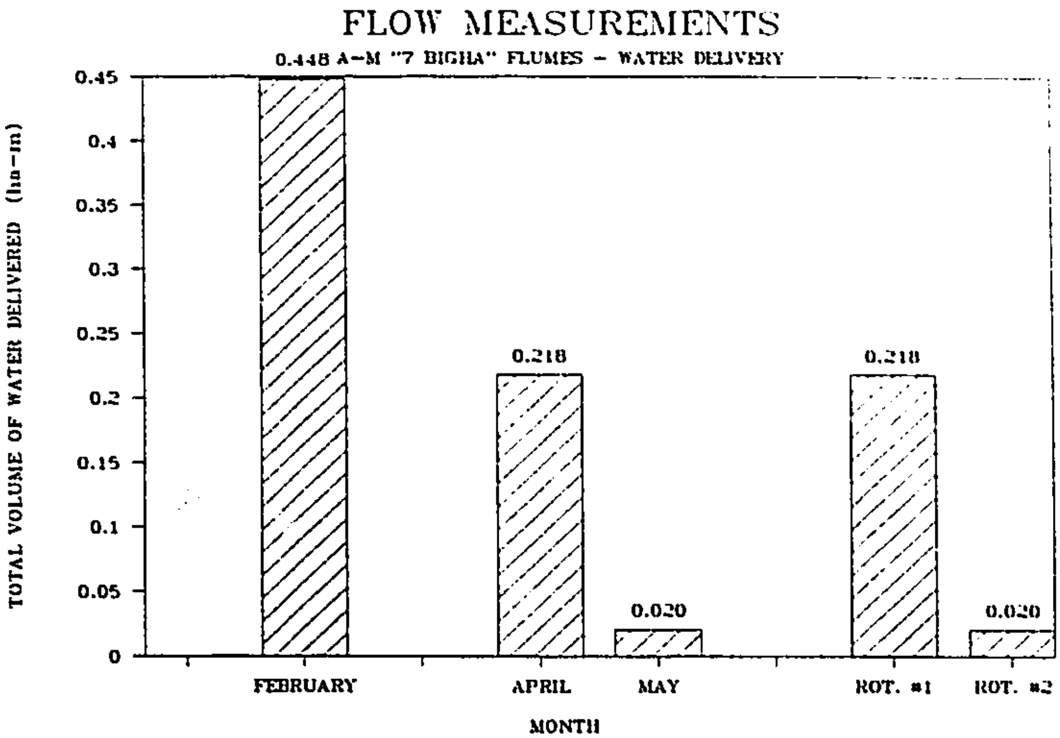

FLOW MEASUREMENTS
SORHA MAUJA MAIN CANAL - JULY, 1989
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
FLOW (cubic metres / second)
01-Jul
05-Jul
09-Jul
13-Jul
17-Jul
21-Jul
25-Jul
29-Jul
02-Aug
DATE

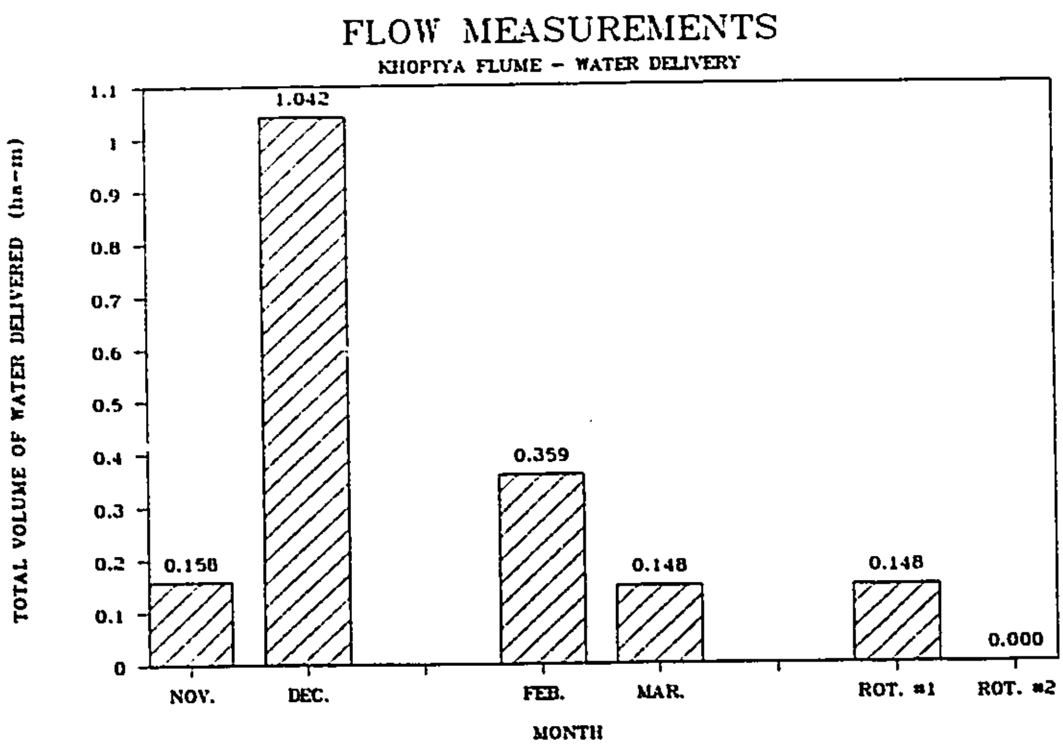

FLOW MEASUREMENTS
WEST SIDDHANAGAR - WATER DELIVERY
TOTAL VOLUME OF WATER DELIVERED (ha-m)
4
3.5
3
2.5
2
1.5
1
0.5
0
2.564
3.217
0.664
0.997
0.590
0.997
0.323
JAN.
FEB.
MARCH
APRIL
MAY
ROT. #1
ROT. #2
MONTH

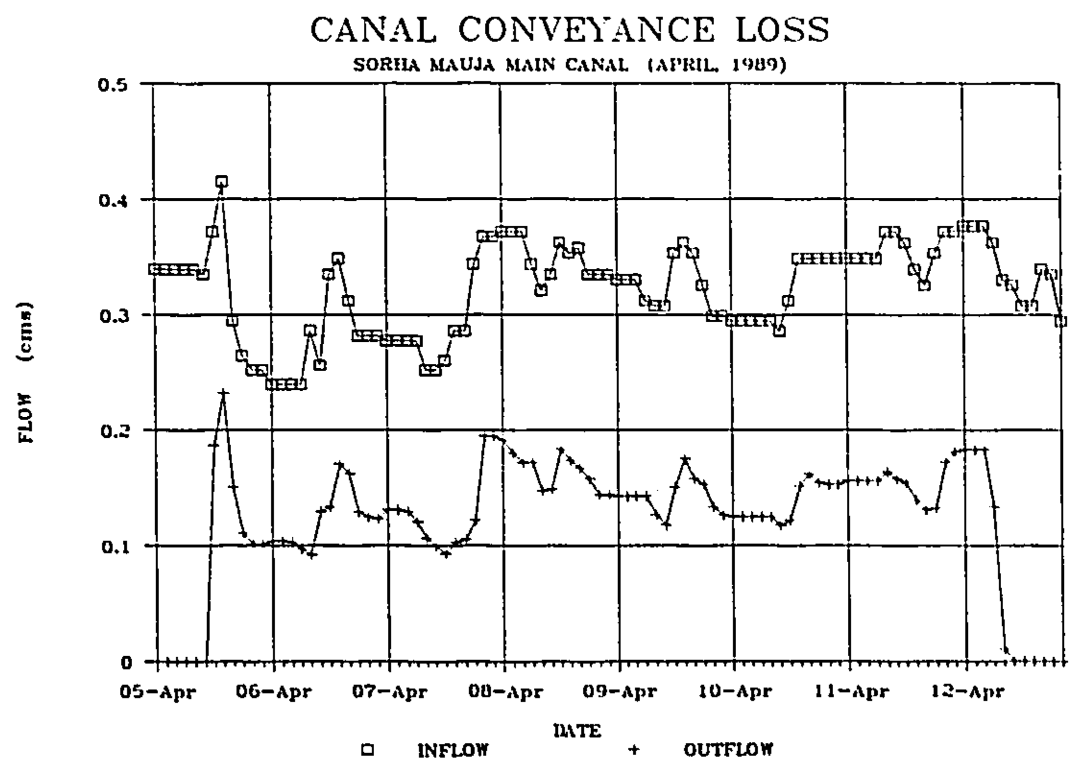

FLOW MEASUREMENTS
A-M MAIN CANAL - WATER DELIVERY
TOTAL VOLUME OF WATER DELIVERED (ha-m)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
18.243
20.236
1.177
8.525
5.157
8.475
5.157
JANUARY
FEBRUARY
MARCH
APRIL
MAY
ROTATION #
ROTATION #2
MONTH

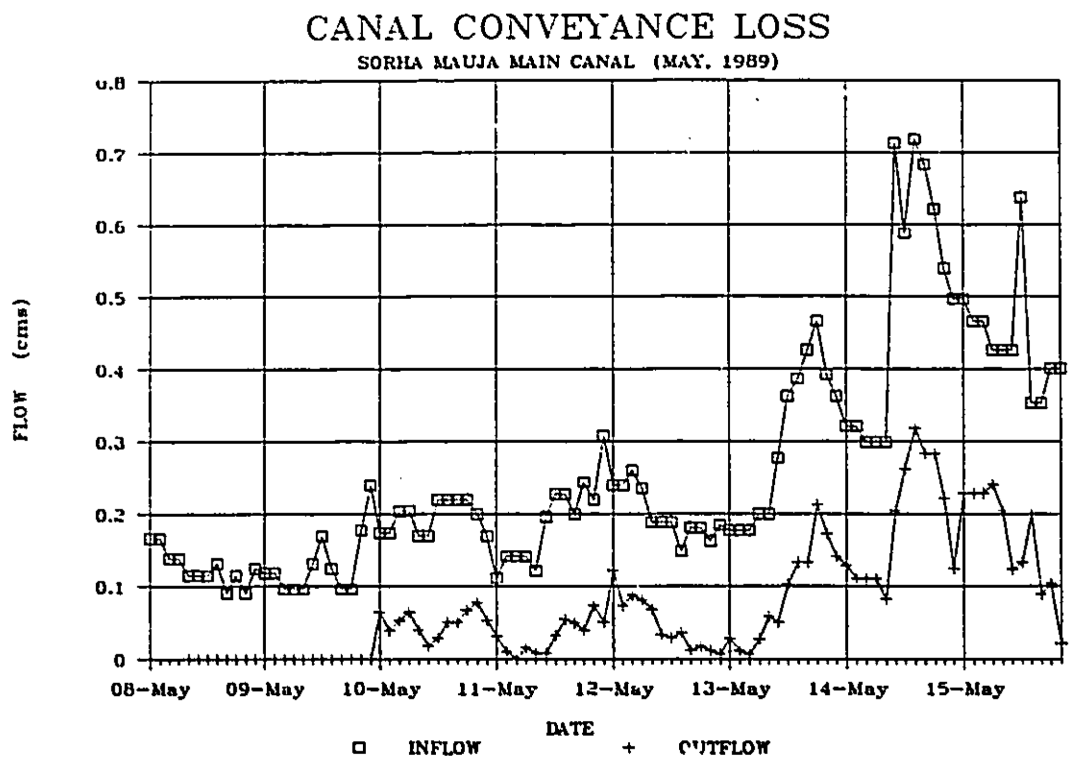


FLOW MEASUREMENTS
A-M #10 WEIR - MONTHLY WATER DELIVERY
TOTAL VOLUME OF WATER DELIVERED (ha-m)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2.406
1.782
0.230
0.741
0.163
0.741
0.163
JAN.
FEB.
MARCH
APRIL
MAY
ROT. #1
ROT. #2
MONTH

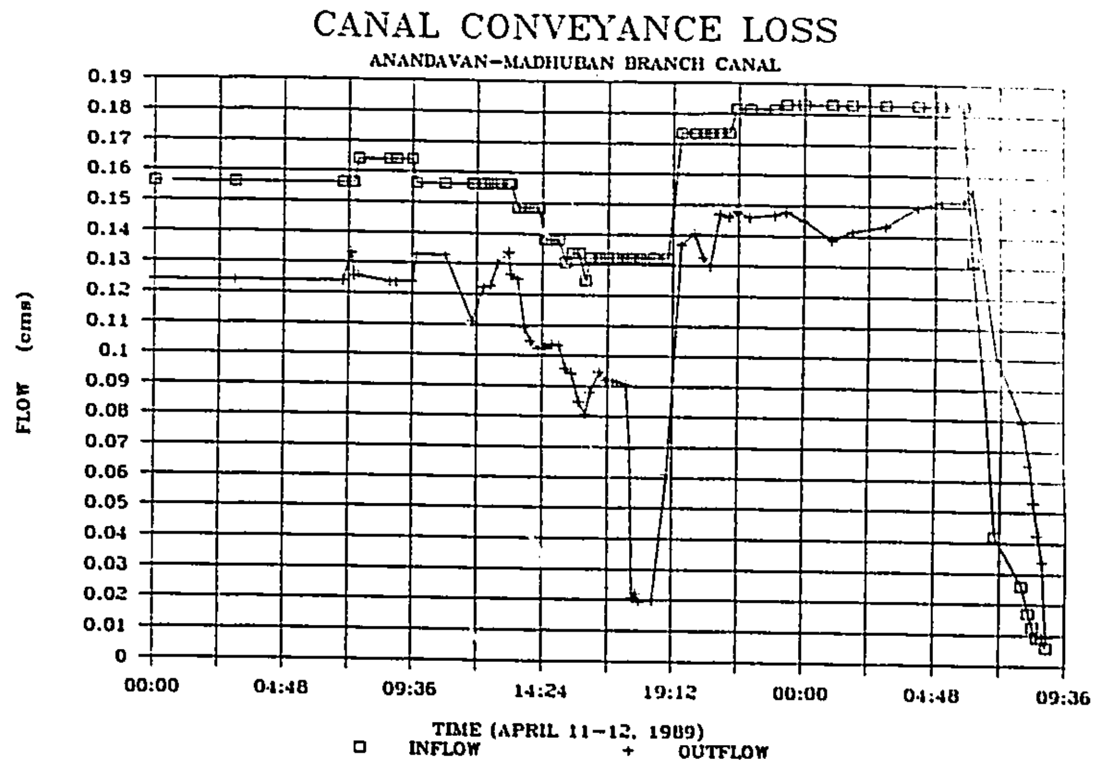

FLOW MEASUREMENTS
0.448 A-M "7 BIGHA" FLUMES - WATER DELIVERY
TOTAL VOLUME OF WATER DELIVERED (ha-m)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.218
0.020
0.218
0.020
FEBRUARY
APRIL
MAY
ROT. #1
ROT. #2
MONTH


FLOW MEASUREMENTS
KHOPIYA FLUME - WATER DELIVERY
TOTAL VOLUME OF WATER DELIVERED (ha-m)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.042
0.158
0.359
0.148
0.148
0.000
NOV.
DEC.
FEB.
MAR.
ROT. #1
ROT. #2
MONTH


CANAL CONVEYANCE LOSS
SORHA MAUJA MAIN CANAL (APRIL, 1989)
FLOW (cms)
0.5
0.4
0.3
0.2
0.1
0
05-Apr
06-Apr
07-Apr
08-Apr
09-Apr
10-Apr
11-Apr
12-Apr
DATE
INFLOW
OUTFLOW



CANAL CONVEYANCE LOSS
SORHA MAUJA MAIN CANAL (MAY, 1989)
FLOW (cms)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
08-May
09-May
10-May
11-May
12-May
13-May
14-May
15-May
DATE
INFLOW
OUTFLOW



CANAL CONVEYANCE LOSS
ANANDAVAN-MADHUBAN BRANCH CANAL
FLOW (cms)
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
00:00
04:48
09:36
14:24
19:12
00:00
04:48
09:36
TIME (APRIL 11-12, 1989)
INFLOW
OUTFLOW

APPENDIX B

IRRIGATIONS FOR WHEAT
WITH CROP WATER REQUIREMENTS

IRRIGATION VS. CWR FOR WHEAT (CROP 2) - WEST SIDDHANAGAR BRANCH

DATE MON	DAY	FARMER	IN.	AREA	DAYS S.P.	APP. #	DAYS SINCE L.A.	DURATION hr	AVE. FLOW (m^3/s)	VOL. (m^3)	IR AP DE (
DEC	24	RAM BAHADUR CHETTRI	1	0.23	27	1		7.5			
DEC	26	RAM BAHADUR CHETTRI	1	0.23	29	2	2				
JAN	9	RAM BAHADUR CHETTRI	1	0.23	43	3	14				
JAN	24	RAM BAHADUR CHETTRI	1	0.23	58	4	5	4.0	0.026	367	
FEB	15	RAM BAHADUR CHETTRI	1	0.23	80	5	32	3.7	0.029	387	
MAR	13	RAM BAHADUR CHETTRI	1	0.23	106	6	26				
DEC	16	RAM BAHADUR CHETTRI	6	0.18	41	1		4.0			
DEC	26	RAM BAHADUR CHETTRI	6	0.18	51	2	10				
JAN	9	RAM BAHADUR CHETTRI	6	0.18	65	3	14				
JAN	24	RAM BAHADUR CHETTRI	6	0.18	80	4	15	1.7	0.026	153	
FEB	15	RAM BAHADUR CHETTRI	6	0.18	102	5	22	3.7	0.024	317	
MAR	13	RAM BAHADUR CHETTRI	6	0.18	128	6	26				
DEC	22	HARSHA BAHADUR BARAL	2	0.27	25	1		2.0			
DEC	26	HARSHA BAHADUR BARAL	2	0.27	29	2	4				
JAN	9	HARSHA BAHADUR BARAL	2	0.27	43	3	14				
JAN	30	HARSHA BAHADUR BARAL	2	0.27	64	4	21	4.0	0.006	92	
FEB	16	HARSHA BAHADUR BARAL	2	0.27	81	5	17	4.2	0.023	342	
MAR	13	HARSHA BAHADUR BARAL	2	0.27	106	6	25				
DEC	18	RAM SINGH RANA	3	0.17	21	2		2.0			
DEC	26	RAM SINGH RANA	3	0.17	29	3	8				
JAN	9	RAM SINGH RANA	3	0.17	43	4	14				
JAN	30	RAM SINGH RANA	3	0.17	64	5	21	5.0	0.009	155	
MAR	13	RAM SINGH RANA	3	0.17	106	6	42				
DEC	16	CHANDRA BAHADUR B.K.	4	0.18	27	1		2.0			
DEC	26	CHANDRA BAHADUR B.K.	4	0.18	37	2	10				
JAN	9	CHANDRA BAHADUR B.K.	4	0.18	51	3	14				
JAN	26	CHANDRA BAHADUR B.K.	4	0.18	68	4	17	4.4	0.019	298	
FEB	17	CHANDRA BAHADUR B.K.	4	0.18	90	5	22	6.5	0.009	199	
MAR	13	CHANDRA BAHADUR B.K.	4	0.18	114	6	24				
DEC	26	SARBAGIT RANA	5	0.14	33	1					
DEC	27	SARBAGIT RANA	5	0.14	34	2	1	1.0			
JAN	9	SARBAGIT RANA	5	0.14	47	3	13				
JAN	26	SARBAGIT RANA	5	0.14	64	4	17	1.5	0.012	62	
MAR	13	SARBAGIT RANA	5	0.14	110	5	46				

. W ^3/s)	VOL. (m^3)	IRR. APP. DEPTH (mm)	RAIN APP. DEPTH (mm)	TOTAL APPL. (mm)	CWR FOR PERIOD (mm)	TOTAL CWR (mm)	% OF CWR PERIOD	% OF CWR OVERALL
		50			12		417%	
			32		8		400%	
			27		14		193%	
026	367	160			36		443%	
029	387	168			55		306%	
			28	465	110	235	25%	198%
		50			34		147%	
			32		17		188%	
			27		19		142%	
026	153	85			55		155%	
024	317	176			66		267%	
			28	398	44	235	64%	170%
		50			12		417%	
			32		8		400%	
			27		14		193%	
006	92	34			36		95%	
023	342	128			55		233%	
			28	299	110	235	25%	127%
		50			12		417%	
			32		8		400%	
			27		14		193%	
009	155	91			36		253%	
			28	228	166	236	17%	97%
		50			20		250%	
			32		14		229%	
			27		17		159%	
019	298	166			47		353%	
009	199	111			53		208%	
			28	413	84	235	33%	176%
			32		20		160%	
		30			14		214%	
			27		17		159%	
012	62	44			47		93%	
			28	161	137	235	20%	68%

IRRIGATION VS. CWR FOR WHEAT (CROP 2) - WEST SIDDHANAGAR BRANCH

DATE MON	DAY	FARMER	IN.	AREA	DAYS S.P.	APP. #	DAYS SINCE L.A.	DURA-TION hr	AVE. FLOW (m^3/s)	VOL. (m^3)
DEC	9	DHAN KUMARI MAGER	8	0.07	22	1		1.5		
DEC	26	DHAN KUMARI MAGER	8	0.07	39	2	17			
JAN	9	DHAN KUMARI MAGER	8	0.07	53	3	14			
MAR	13	DHAN KUMARI MAGER	8	0.07	116	4	63			
DEC	18	BHAKTA BAHADUR K.C.	9	0.17	18	1		2.0		
DEC	26	BHAKTA BAHADUR K.C.	9	0.17	26	2	8			
JAN	9	BHAKTA BAHADUR K.C.	9	0.17	40	3	14			
JAN	25	BHAKTA BAHADUR K.C.	9	0.17	55	4	15	15.0	0.011	578
JAN	26	BHAKTA BAHADUR K.C.	9	0.17	56	CONT	16	9.0	0.011	347
MAR	13	BHAKTA BAHADUR K.C.	9	0.17	103	5	47			
DEC	26	BHAKTA BAHADUR K.C.	23	0.08	19	1				
JAN	9	BHAKTA BAHADUR K.C.	23	0.08	33	2	14			
MAR	13	BHAKTA BAHADUR K.C.	23	0.08	96	3	63			
DEC	26	DHAN BAHADUR MAGI	10	0.27	28	1				
JAN	9	DHAN BAHADUR MAGI	10	0.27	42	2	14			
JAN	28	DHAN BAHADUR MAGI	10	0.27	67	3	19	4.8	0.010	171
MAR	13	DHAN BAHADUR MAGI	10	0.27	105	4	44			
DEC	13	DHAN BAHADUR PUN	11	0.10	27	1		2.0		
DEC	26	DHAN BAHADUR PUN	11	0.10	40	2	13			
JAN	9	DHAN BAHADUR PUN	11	0.10	54	3	14			
JAN	27	DHAN BAHADUR PUN	11	0.10	72	4	18	3.5	0.017	214
MAR	13	DHAN BAHADUR PUN	11	0.10	117	5	45			

VE. LOW (m^3/s)	VOL. (m^3)	IRR. APP. DEPTH (mm)	RAIN APP. DEPTH (mm)	TOTAL APPL. (mm)	CWR FOR PERIOD (mm)	TOTAL CWR (mm)	% OF CWR PERIOD	% OF CWR OVERALL
		50			12		417%	
			32		22		145%	
			27		17		159%	
			28	137	184	235	15%	58%
		50			12		417%	
			32		8		400%	
			27		14		193%	
0.011	578	347			17		2039%	
0.011	347	208			19		1095%	
			28	692	165	235	17%	294%
			32		12		267%	
			27		22		123%	
			28	87	201	235	14%	37%
			32		20		160%	
			27		14		193%	
0.010	171	64			64		100%	
			28	151	137	235	20%	64%
		50			20		250%	
			32		14		229%	
			27		17		159%	
0.017	214	214			47		456%	
			28	351	137	235	20%	149%

IRRIGATION VS. CWR FOR WHEAT (CROP 2) - WEST SIDDHANAGAR BRANCH

DATE MON	DAY	FARMER	IN.	AREA	DAYS S.P.	APP. #	DAYS SINCE L.A.	DURA-TION hr	AVE. FLOW (m^3/s)	VOL. (m^3)	I A D
DEC	21	TARA PRASAD NEUPANE	12	0.07	21	1		1.0			
DEC	26	TARA PRASAD NEUPANE	12	0.07	26	2	5				
JAN	9	TARA PRASAD NEUPANE	12	0.07	40	3	14				
JAN	26	TARA PRASAD NEUPANE	12	0.07	57	4	17	2.0	0.023	163	
MAR	13	TARA PRASAD NEUPANE	12	0.07	103	5	46				
DEC	19	MANI RAM CHETTRI	14	0.33	22	1		5.0			
DEC	26	MANI RAM CHETTRI	14	0.33	29	2	7				
JAN	9	MANI RAM CHETTRI	14	0.33	43	3	14				
JAN	27	MANI RAM CHETTRI	14	0.33	61	4	18	5.0	0.012	216	
MAR	13	MANI RAM CHETTRI	14	0.33	106	5	45				
DEC	12	JANGA BAHADUR SHAH	16/1	0.53	20	1		8.0			
DEC	26	JANGA BAHADUR SHAH	16/1	0.53	34	2	14				
JAN	9	JANGA BAHADUR SHAH	16/1	0.53	48	3	14				
JAN	19	JANGA BAHADUR SHAH	16/1	0.53	58	4	10	4.8	0.041	706	
FEB	3	JANGA BAHADUR SHAH	16/1	0.53	73	5	15	5.0	0.038	669	
FEB	15	JANGA BAHADUR SHAH	16/1	0.53	85	6	12	5.0	0.046	828	
FEB	24	JANGA BAHADUR SHAH	16/1	0.53	94	7	9	5.2	0.038	711	
MAR	13	JANGA BAHADUR SHAH	16/1	0.53	111	8	17				
DEC	21	SHASI PUN	18	0.10	21	1		8.0			
DEC	26	SHASI PUN	18	0.10	26	2	5				
JAN	9	SHASI PUN	18	0.10	40	3	14				
FEB	3	SHASI PUN	18	0.10	65	4	25	3.8	0.019	258	
MAR	13	SHASI PUN	18	0.10	103	5	38				
DEC	17	BEJ NATH DUMRE	19	0.33	15	1		7.0			
DEC	26	BEJ NATH DUMRE	19	0.33	24	2	9				
JAN	9	BEJ NATH DUMRE	19	0.33	38	3	14				
JAN	20	BEJ NATH DUMRE	19	0.33	49	4	11	3.5	0.034	431	
FEB	10	BEJ NATH DUMRE	19	0.33	70	5	21	5.5	0.024	479	
FEB	24	BEJ NATH DUMRE	19	0.33	84	6	14	3.3	0.054	632	
MAR	13	BEJ NATH DUMRE	19	0.33	101	7	17				
DEC	26	PITHAMBER NEUPANE	20	0.13	16	1					
JAN	9	PITHAMBER NEUPANE	20	0.13	30	2	14				
FEB	10	PITHAMBER NEUPANE	20	0.13	62	3	32	3.3	0.025	295	
FEB	24	PITHAMBER NEUPANE	20	0.13	76	4	14	1.7	0.017	102	
MAR	13	PITHAMBER NEUPANE	20	0.13	93	5	17				

H

AVE. FLOW (m^3/s)	VOL. (m^3)	IRR. APP. DEPTH (mm)	RAIN APP. DEPTH (mm)	TOTAL APPL. (mm)	CWR FOR PERIOD (mm)	TOTAL CWR (mm)	% OF CWR PERIOD	% OF CWR OVERALL
		50			12		417%	
			32		8		400%	
			27		14		193%	
0.023	163	244			36		678%	
			28	381	165	235	17%	162%
		50			12		417%	
			32		8		400%	
			27		14		193%	
0.012	216	65			36		180%	
			28	202	165	235	17%	86%
		50			12		417%	
			32		8		400%	
			27		31		87%	
0.041	706	132			19		697%	
0.038	669	129			28		462%	
0.046	828	155			27		575%	
0.038	711	133			26		513%	
			28	605	84	235	33%	258%
		50			12		417%	
			32		8		400%	
			27		14		193%	
0.019	258	258			36		716%	
			28	395	165	235	17%	168%
		50			12		417%	
			32		8		400%	
			27		14		193%	
0.034	431	129			17		760%	
0.024	479	144			47		306%	
0.054	632	190			53		358%	
			28	550	84	235	33%	234%
			32		12		267%	
			27		8		338%	
0.025	295	227			50		454%	
0.017	102	79			55		143%	
			28	392	110	235	25%	167%

IRRIGATION VS. CWR FOR WHEAT (CROP 2) - WEST SIDDHANAGAR BRANCH

DATE MON	DAY	FARMER	IN.	AREA	DAYS S.P.	APP. #	DAYS SINCE L.A.	DURA-TION hr	AVE. FLOW (m^3/s)	VOL. (m^3)
DEC	26	SAMALATA PUDHAL	21	0.17	35	1				
JAN	5	SAMALATA PUDHAL	21	0.17	45	2	10			
JAN	9	SAMALATA PUDHAL	21	0.17	49	3	4			
MAR	13	SAMALATA PUDHAL	21	0.17	112	4	63			
DEC	17	TIKA RAM NEUPANE	22	0.19	17	1		5.0		
DEC	26	TIKA RAM NEUPANE	22	0.19	26	2	9			
JAN	9	TIKA RAM NEUPANE	22	0.19	40	3	14			
FEB	4	TIKA RAM NEUPANE	22	0.19	66	4	26	8.0	0.012	337
MAR	13	TIKA RAM NEUPANE	22	0.19	103	5	37			
DEC	21	DAMBER BAHADUR PUDHAL	25	0.13	26	1		2.0		
DEC	26	DAMBER BAHADUR PUDHAL	25	0.13	31	2	5			
JAN	9	DAMBER BAHADUR PUDHAL	25	0.13	45	3	14			
FEB	1	DAMBER BAHADUR PUDHAL	25	0.13	68	4	42	14.5	0.006	334
FEB	2	DAMBER BAHADUR PUDHAL	25	0.13	69	CONT	43	14.0	0.006	323
MAR	13	DAMBER BAHADUR PUDHAL	25	0.13	108	5	39			
DEC	20	NUR BAHADUR GURUNG	26	0.13	25	1		3.0		
DEC	26	NUR BAHADUR GURUNG	26	0.13	32	2	6			
JAN	9	NUR BAHADUR GURUNG	26	0.13	45	3	14			
JAN	29	NUR BAHADUR GURUNG	26	0.13	65	4	20	4.5	0.019	313
FEB	25	NUR BAHADUR GURUNG	26	0.13	92	5	27	5.0	0.035	635
MAR	13	NUR BAHADUR GURUNG	26	0.13	108	6	16			
DEC	19	REASI RAM PANDAY	27	0.43	23	1		8.0		
DEC	26	REASI RAM PANDAY	27	0.43	30	2	7			
JAN	9	REASI RAM PANDAY	27	0.43	44	3	14			
JAN	30	REASI RAM PANDAY	27	0.43	65	4	21	7.5	0.007	184
JAN	31	REASI RAM PANDAY	27	0.43	66	CONT	43	10.5	0.008	314
FEB	14	REASI RAM PANDAY	27	0.43	80	5	14	3.0	0.043	468
MAR	13	REASI RAM PANDAY	27	0.43	107	6	27			
DEC	15	DEVI LAL PUDHAL	28	0.18	17	1		4.0		
DEC	26	DEVI LAL PUDHAL	28	0.18	28	2	11			
JAN	9	DEVI LAL PUDHAL	28	0.18	42	3	14			
JAN	28	DEVI LAL PUDHAL	28	0.18	61	4	19	9.0	0.015	492
FEB	14	DEVI LAL PUDHAL	28	0.18	78	5	17	2.2	0.042	325
MAR	13	DEVI LAL PUDHAL	28	0.18	105	6	27			

VE. LOW m^3/s)	VOL. (m^3)	IRR. APP. DEPTH (mm)	RAIN APP. DEPTH (mm)	TOTAL APPL. (mm)	CWR FOR PERIOD (mm)	TOTAL CWR (mm)	% OF CWR PERIOD	% OF CWR OVERALL
			32		20		160%	
		100			14		714%	
			27		17		159%	
			28	187	184	235	15%	80%
		50			12		417%	
			32		8		400%	
			27		14		193%	
0.012	337	179			64		280%	
			28	316	137	235	20%	134%
		50			12		417%	
			32		8		400%	
			27		31		87%	
0.006	334	251			19		1319%	
0.006	323	242			28		864%	
			18	619	137	235	13%	264%
		50			12		417%	
			32		8		400%	
			27		31		87%	
0.019	313	241			47		512%	
0.035	635	489			53		922%	
			28	866	84	235	33%	369%
		50			12		417%	
			32		8		400%	
			27		14		193%	
0.007	184	42			36		118%	
0.008	314	72			28		259%	
0.043	468	108			27		400%	
			28	310	110	235	25%	132%
		50			12		417%	
			32		8		400%	
			27		14		193%	
0.015	492	281			36		782%	
0.042	325	186			55		338%	
			28	604	110	235	25%	257%

IRRIGATION VS. CWR FOR WHEAT (CROP 2) - ANANDAVAN-MADHUBAN No. 10 SUB-BRA

DATE MON	DAY	FARMER	IN.	AREA	DAYS SINCE PLANT	APP. #	DAYS SINCE L.A.	DURA-TION hr	AVE. FLOW (m^3/s)	DE OF IR (
DEC	15	MADHAB PATHAK	A1/3	0.60	15	1		6		
DEC	26	MADHAB PATHAK	A1/3	0.60	26	2	11			
JAN	9	MADHAB PATHAK	A1/3	0.60	40	3	14			
FEB	5	MADHAB PATHAK	A1/3	0.60	67	4	27	7	0.023	
MAR	13	MADHAB PATHAK	A1/3	0.60	103	5	36			
DEC	18	SHREE PRASAD BHUSHAL	B1	0.02	18	1		3		
DEC	26	SHREE PRASAD BHUSHAL	B1	0.02	26	2	8			
JAN	9	SHREE PRASAD BHUSHAL	B1	0.02	40	3	14			
FEB	6	SHREE PRASAD BHUSHAL	B1	0.02	68	4	28	3.75	0.06	
MAR	13	SHREE PRASAD BHUSHAL	B1	0.02	103	5	35			
DEC	18	BUDDHI PRASAD PATHAK	B2	0.48	23	1		4		
DEC	26	BUDDHI PRASAD PATHAK	B2	0.48	31	2	8			
JAN	9	BUDDHI PRASAD PATHAK	B2	0.48	45	3	14			
FEB	6	BUDDHI PRASAD PATHAK	B2	0.48	72	4	27	5	0.05	
MAR	13	BUDDHI PRASAD PATHAK	B2	0.48	108	5	35			
DEC	21	KHAM RAJ PATHAK	B3/5	0.23	26	1		6		
DEC	26	KHAM RAJ PATHAK	B3/5	0.23	31	2	5			
JAN	9	KHAM RAJ PATHAK	B3/5	0.23	45	3	14			
FEB	10	KHAM RAJ PATHAK	B3/5	0.23	77	4	32	3	0.01	
MAR	13	KHAM RAJ PATHAK	B3/5	0.23	108	5	31			
DEC	12	NANDA LAL RIJAL	A4	0.50	22	1		7		
DEC	26	NANDA LAL RIJAL	A4	0.50	36	2	14			
JAN	9	NANDA LAL RIJAL	A4	0.50	50	3	14			
FEB	1	NANDA LAL RIJAL	A4	0.50	73	4	23	4	0.012	
MAR	13	NANDA LAL RIJAL	A4	0.50	113	5	39			
DEC	24	NILA KANTA PATHAK	B7	0.67	24	1		8		
DEC	26	NILA KANTA PATHAK	B7	0.67	26	2	2			
JAN	9	NILA KANTA PATHAK	B7	0.67	40	3	14			
FEB	6	NILA KANTA PATHAK	B7	0.67	68	4	27	?		
MAR	13	NILA KANTA PATHAK	B7	0.67	103	5	34			
DEC	24	KESHARI LAL BHANDARI	B6	0.67	25	1		24		
DEC	26	KESHARI LAL BHANDARI	B6	0.67	27	2	2			
JAN	9	KESHARI LAL BHANDARI	B6	0.67	41	3	14			
FEB	2	KESHARI LAL BHANDARI	B6	0.67	65	4	24	11.5	0.013	
MAR	13	KESHARI LAL BHANDARI	B6	0.67	104	5	39			

E T	APP. #	DAYS SINCE L.A.	DURATION hr	AVE. FLOW (m^3/s)	DEPTH OF APP. IRR. (mm)	RAIN (mm)	TOTAL APPL.	TOTAL CWR	% OF CWR
5	1		6		50				
6	2	11				32			
)	3	14				37			
7	4	27	7	0.023	97				
5	5	36				28	244	235	104%
3	1		3		50				
6	2	8				32			
)	3	14				27			
3	4	28	3.75	0.06	4860				
3	5	35				28	4997	235	2126%
5	1		4		50				
l	2	8				32			
5	3	14				27			
2	4	27	5	0.05	186				
3	5	35				28	323	235	138%
6	1		6		50				
l	2	5				32			
5	3	14				27			
7	4	32	3	0.01	46				
3	5	31				28	183	235	78%
2	1		7		50				
6	2	14				32			
)	3	14				27			
5	4	23	4	0.012	35				
5	5	39				28	172	235	73%
4	1		8		50				
6	2	2				32			
)	3	14				27			
3	4	27	?						
5	5	34				28	137	235	58%
5	1		24		50				
7	2	2				32			
l	3	14				27			
5	4	24	11.5	0.013	81				
4	5	39				28	218	235	93%

IRRIGATION VS. CWR FOR WHEAT (CROP 2) - ANANDAVAN-MADHUBAN No. 10 SUB-BRANCH

DATE MON	DAY	FARMER	IN.	AREA	DAYS SINCE PLANT	APP. #	DAYS SINCE L.A.	DURA-TION hr	AVE. FLOW (m^3/s)	DEPTH OF APP IRR. (mm)
DEC	22	PURNA KALA PATHAK	B11	0.28	17	1		9		50
DEC	26	PURNA KALA PATHAK	B11	0.28	21	2	4			
JAN	9	PURNA KALA PATHAK	B11	0.28	35	3	14			
FEB	13	PURNA KALA PATHAK	B11	0.28	70	4	35	5.75	0.018	132
MAR	13	PURNA KALA PATHAK	B11	0.28	98	5	28			
DEC	15	GIRI RAJ PATHAK	A5	0.40	29	1		7		50
DEC	26	GIRI RAJ PATHAK	A5	0.40	40	2	11			
JAN	9	GIRI RAJ PATHAK	A5	0.40	54	3	14			
FEB	5	GIRI RAJ PATHAK	A5	0.40	81	4	27	7	0.05	315
MAR	13	GIRI RAJ PATHAK	A5	0.40	117	5	36			
DEC	13	MUKTI PRASAD PATHAK	A5	0.60	15	1		9		50
DEC	26	MUKTI PRASAD PATHAK	A5	0.60	28	2	13			
JAN	9	MUKTI PRASAD PATHAK	A5	0.60	42	3	14			
FEB	5	MUKTI PRASAD PATHAK	A5	0.60	69	4	27	15.5	0.028	260
MAR	13	MUKTI PRASAD PATHAK	A5	0.60	105	5	36			
DEC	16	AKADHAU REGEMI	A10	0.17	19	1		1		50
DEC	26	AKADHAU REGEMI	A10	0.17	29	2	10			
JAN	9	AKADHAU REGEMI	A10	0.17	43	3	14			
JAN	28	AKADHAU REGEMI	A10	0.17	62	4	19	?		
MAR	13	AKADHAU REGEMI	A10	0.17	106	5	44			
DEC	15	TEK BAHADUR SEMARAY	A8	0.07	24	1		0.5		50
DEC	26	TEK BAHADUR SEMARAY	A8	0.07	34	2	10			
JAN	9	TEK BAHADUR SEMARAY	A8	0.07	48	3	14			
FEB	8	TEK BAHADUR SEMARAY	A8	0.07	78	4	30	4.5	0.005	122
MAR	13	TEK BAHADUR SEMARAY	A8	0.07	111	5	33			
DEC	26	MAN BAHADUR MAGER	A9	0.10	27	1				
JAN	9	MAN BAHADUR MAGER	A9	0.10	41	2	14			
FEB	11	MAN BAHADUR MAGER	A9	0.10	74	3	33	1.5	0.006	32
MAR	13	MAN BAHADUR MAGER	A9	0.10	104	4	30			
DEC	21	BENI MADHAB ADHIKARI	A7	0.02	29	1		0.33		50
DEC	26	BENI MADHAB ADHIKARI	A7	0.02	34	2	5			
JAN	9	BENI MADHAB ADHIKARI	A7	0.02	48	3	14			
FEB	7	BENI MADHAB ADHIKARI	A7	0.02	77	4	29	27.5	0.001	440
MAR	13	BENI MADHAB ADHIKARI	A7	0.02	111	6	33			

AVAN-MADHUBAN No. 10 SUB-BRANCH

E T	APP. #	DAYS SINCE L.A.	DURATION hr	AVE. FLOW (m^3/s)	DEPTH OF APP. IRR. (mm)	RAIN (mm)	TOTAL APPL.	TOTAL CWR	% OF CWR
7	1		9		50				
1	2	4				32			
5	3	14				27			
0	4	35	5.75	0.018	132				
8	5	28				28	269	235	114%
9	1		7		50				
0	2	11				32			
4	3	14				27			
1	4	27	7	0.05	315				
7	5	36				28	452	235	192%
5	1		9		50				
8	2	13				32			
2	3	14				27			
9	4	27	15.5	0.028	260				
5	5	36				28	397	235	169%
9	1		1		50				
9	2	10				32			
3	3	14				27			
2	4	19	?						
6	5	44				28	137	235	58%
4	1		0.5		50				
4	2	10				32			
8	3	14				27			
8	4	30	4.5	0.005	122				
1	5	33				28	259	235	110%
7	1					32			
1	2	14				27			
4	3	33	1.5	0.006	32				
4	4	30				28	119	235	51%
9	1		0.33		50				
4	2	5				32			
8	3	14				27			
7	4	29	27.5	0.001	440				
1	6	33				28	577	235	246%

IRRIGATION VS. CWR FOR WHEAT (CROP 2) - ANANDAVAN-MADHUBAN "7 BIGHA" SUB-

DATE MON	DAY	FARMER	IN.	CROP	AREA	IRR/ RAIN	DAYS S.P.	APP. #	DAYS SINCE L.A.	DURATION hr
DEC	15	KHAGA NATH BHANDARI	1	WHEAT	0.73	IRR	23	1		
DEC	26	KHAGA NATH BHANDARI	1	WHEAT	0.73	RAIN	34	2	11	
JAN	9	KHAGA NATH BHANDARI	1	WHEAT	0.73	RAIN	48	3	14	
FEB	5	KHAGA NATH BHANDARI	1	WHEAT	0.73	IRR	75	4	27	16.5
MAR	13	KHAGA NATH BHANDARI	1	WHEAT	0.73	RAIN	111	5	35	
DEC	15	BENI MADHAB ADHIKARI	2	WHEAT	0.53	IRR	23	1		
DEC	26	BENI MADHAB ADHIKARI	2	WHEAT	0.53	RAIN	34	2	11	
JAN	9	BENI MADHAB ADHIKARI	2	WHEAT	0.53	RAIN	48	3	14	
FEB	7	BENI MADHAB ADHIKARI	2	WHEAT	0.53	IRR	77	4	29	10.25
MAR	13	BENI MADHAB ADHIKARI	2	WHEAT	0.53	RAIN	111	5	33	
DEC	15	TEK BAHADUR SAMARY	3	WHEAT	0.30	IRR	23	1		
DEC	26	TEK BAHADUR SAMARY	3	WHEAT	0.30	RAIN	34	2	11	
JAN	9	TEK BAHADUR SAMARY	3	WHEAT	0.30	RAIN	48	3	14	
FEB	8	TEK BAHADUR SAMARY	3	WHEAT	0.30	IRR	78	4	30	11
MAR	13	TEK BAHADUR SAMARY	3	WHEAT	0.30	RAIN	111	5	33	
DEC	26	MAN BAHADUR MAGAR	7	WHEAT	0.33	RAIN	27	1		
DEC	30	MAN BAHADUR MAGAR	7	WHEAT	0.33	IRR	31	2	3	
JAN	9	MAN BAHADUR MAGAR	7	WHEAT	0.33	RAIN	41	3	10	
FEB	8	MAN BAHADUR MAGAR	7	WHEAT	0.33	IRR	71	4	30	12.75
MAR	13	MAN BAHADUR MAGAR	7	WHEAT	0.33	RAIN	104	5	32	

IUBAN "7 BIGHA" SUB-BRANCH

'S P.	APP. #	DAYS SINCE L.A.	DURA-TION hr	VOL. DEL.	DEPTH OF APP. IRR. (mm)	RAIN (mm)	TOTAL APP. (mm)	TOTAL CWR (mm)	% OF CWR
23	1				50				
54	2	11				32			
18	3	14				27			
'5	4	27	16.5	1317.7	180				
.1	5	35				28	317	235	135%
23	1				50				
54	2	11				32			
18	3	14				27			
'7	4	29	10.25	433.2	81				
.1	5	33				28	218	235	93%
23	1				50				
54	2	11				32			
18	3	14				27			
'8	4	30	11	192.3	64				
.1	5	33				28	201	235	86%
27	1					32			
51	2	3			50				
11	3	10				27			
'1	4	30	12.75	368.1	112				
)4	5	32				28	249	235	106%

IRRIGATION VS. CWR FOR WHEAT (CROP 2) - KHOPIYA BRANCH

DATE MON	DAY	FARMER	AREA	DAYS S.P.	APP. #	DAYS SINCE L.A.	VOL. DEL. (m^3)	DEPTH OF APP. IRR. (mm)	RAIN (mm)
DEC	26	PASUPATI UPADHYA	1.10	34	1				3
JAN	9	PASUPATI UPADHYA	1.10	48	2	14			2
FEB	21	PASUPATI UPADHYA	1.10	91	3	43	217.8	20	
MAR	13	PASUPATI UPADHYA	1.10	111	4	20			2
DEC	26	MUKTI NATH UPADHYA	0.23	40	1				3
JAN	9	MUKTI NATH UPADHYA	0.23	54	2	14			2
FEB	22	MUKTI NATH UPADHYA	0.23	98	3	44	329.3	143	
MAR	13	MUKTI NATH UPADHYA	0.23	117	4	18			2
MAR	27	MUKTI NATH UPADHYA	0.23	131	5	14	658.9	286	
DEC	18	HARI BAHADUR KHADKA	0.07	26	1			50	
DEC	26	HARI BAHADUR KHADKA	0.07	34	2	7			3
JAN	9	HARI BAHADUR KHADKA	0.07	48	3	14			2
MAR	13	HARI BAHADUR KHADKA	0.07	111	4	63			2
DEC	26	JIT BAHADUR BUDHATHOKI	1.00	20	1		2000	200	
DEC	26	JIT BAHADUR BUDHATHOKI	1.00	20	2				3
JAN	9	JIT BAHADUR BUDHATHOKI	1.00	34	3	14			2
MAR	13	JIT BAHADUR BUDHATHOKI	1.00	97	4	63			2
DEC	26	DHARMA PRASAD TIMILSEMA	0.33	13	1				3
JAN	9	DHARMA PRASAD TIMILSEMA	0.33	27	2	14			2
FEB	21	DHARMA PRASAD TIMILSEMA	0.33	70	3	43	560.5	170	
MAR	13	DHARMA PRASAD TIMILSEMA	0.33	90	4	19			2
DEC	18	GYA NARAYAN SHARMA	0.50	14	1			50	
DEC	26	GYA NARAYAN SHARMA	0.50	25	2	11			3
JAN	9	GYA NARAYAN SHARMA	0.50	39	3	14			2
FEB	20	GYA NARAYAN SHARMA	0.50	81	4	42	1036.8	207	
MAR	13	GYA NARAYAN SHARMA	0.50	102	5	21			2
DEC	18	CHANDRA PRASAD SHARMA	0.33	23	1				
DEC	26	CHANDRA PRASAD SHARMA	0.33	34	2	11			3
JAN	9	CHANDRA PRASAD SHARMA	0.33	48	3	14			2
FEB	20	CHANDRA PRASAD SHARMA	0.33	90	4	42	612.6	184	
MAR	13	CHANDRA PRASAD SHARMA	0.33	111	5	19			2

VOL. DEL. (m^3)	DEPTH OF APP. IRR. (mm)	RAIN (mm)	TOTAL APP. (mm)	TOTAL CWR (mm)	% OF CWR
		32			
		27			
217.8	20				
		28	107	235	45%
		32			
		27			
329.3	143				
		28			
658.9	286		517	235	220%
	50				
		32			
		27			
		28	137	235	58%
2000	200				
		32			
		27			
		28	287	235	122%
		32			
		27			
560.5	170				
		28	257	235	109%
	50				
		32			
		27			
1036.8	207				
		28	344	235	147%
		32			
		27			
612.6	184				
		28	271	235	115%

REFERENCES

Abernethy, C.L. 1989. Performance criteria for irrigation systems. Unpublished report, International Irrigation Management Institute, Dignana Village, Sri Lanka.

American Society of Agricultural Engineers (ASAE). 1983. Design and operation of farm irrigation systems. 2nd ed. ASAE Monograph Number 3, M.E. Jensen ed., ASAE, St. Joseph, Michigan.

Asian Development Bank and His Majesty's Government of Nepal (ADB/HMGN). 1982. Nepal agriculture sector strategy study (Volumes 1 and 2). Asian Development Bank, Manila, Philippines.

Bell, William. 1988. Personal communication, Kathmandu, Nepal.

Berthery, D. 1986. Performance evaluation: a people oriented approach. Unpublished notes, International Irrigation Management Institute (IIMI), Digana Village, Sri Lanka.

Biswas, Asit K. 1989. Irrigation in Nepal: opportunities and constraints. The Journal of Irrigation and Drainage Engineering, ASCE, Volume 115, Number 6.

Bos, M.G. and J. Nugteren. 1978. On irrigation efficiencies. Publication 19, International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands.

Canadian International Development Agency (CIDA). 1989. Nepal Posting Report. CIDA, Hull.

Canadian International Water and Energy Consultants (CIWEC). 1989. Master plan for irrigation development in Nepal (working paper no. 1, present level of irrigation development, working paper no. 9, agricultural background, working paper no. 17, master plan food production targets). Unpublished report, CIWEC, Kathmandu, Nepal.

Chambers, R. 1988. Managing canal irrigation. Oxford and IBH Publishing Company, New Delhi.

Chaudary, N.K. 1989. Critical growth stages of wheat, personal communication, IAAS, Rampur, Nepal.

Dastane, N.G. 1974. Effective rainfall. FAO irrigation and drainage paper No. 25, FAO, Rome.

Doneen, L.D. and D.W. Westcot. 1988. Irrigation practice and water management. Oxford and IBH Publishing Company, New Delhi.

Doorenbos, J. and W.O. Pruitt. 1977. Guidelines for predicting crop water requirements. Food and Agriculture Organization of the United Nations, Rome.

Economist Intelligence Unit (EIU). 1987. Country profile: India, Nepal 1987-88. The Economist Intelligence Unit, London.

Hillel, Daniel. 1987. The efficient use of water in irrigation: principles and practices for improving irrigation in arid and semiarid regions. World Bank Technical Paper Number 64, The World Bank, Washington.

International Irrigation Management Institute (IIMI). 1987. Irrigation management in Nepal, research papers from a national seminar. IIMI, Kathmandu.

International Irrigation Management Institute (IIMI). 1986. Miscellaneous working papers on measure of irrigation system performance. Unpublished report, International Irrigation Management Institute, Dignana Village, Sri Lanka.

International Food Policy Research Institute (IFPRI). 1988. Assessing irrigation system performance. Unpublished paper, IFPRI, Washington.

Kay, Melvyn. 1986. Surface irrigation systems and practice. Cranfield Press, Cranfield Bedford, England.

Kenting Earth Sciences Limited. 1986. Land utilization report, Nepal land resources mapping project (LRMP), Ottawa.

Krogman, K.K. and E.H. Hobbs. 1978. Scheduling irrigation to meet crop demands. Agriculture Canada, Ottawa.

Misra, R.D. and M. Ahmed. 1987. Manual on irrigation agronomy. Oxford and IBH Publishing, New Delhi.

Ng, Pok-Kok. 1987. A methodology for monitoring and evaluating the performance of lowland rice irrigation systems: reliability, resiliency, and vulnerability criteria for assessing water adequacy and the impact of investment to improve the performance of irrigation projects. International Irrigation Management Institute, Digana Village, Sri Lanka.

Pathak, Madhab. 1989. Personal communication, Anandavan Madhuban, Nepal.

Podmore, C.A. 1983. Diagnostic analysis of irrigation systems, volume 1: concepts and methodology. Colorado State University, Fort Collins.

Pradhan, Ujjwal. 1985. The role of the state and property rights in irrigated agriculture in Nepal. Unpublished paper, Cornell University, Ithaca, New York.

Reddi, G.H. 1976. Management of irrigation water. Andhra Pradesh Agrucultural University, Rajendrangar, India.

Replogle, John; Marinus Bos and Albert Clemmens. 1984. Flow measuring flumes for open channel systems. John Wiley and Sons, Toronto.

Sally, Hilmy. 1986 Boundaries. A discussion paper presented at the IIMI Internal Workshop on Performance Evaluation, Digana Village, Sri Lanka.

Simon, Andrew L. 1986. Hydraulics. John Wiley and Sons, Toronto.

Sir M MacDonald and Partners Ltd. 1988. Assistance in the establishment of design criteria and manuals for irrigation projects in Nepal, design philosophy and approach manual. Unpublished report, Sir M MacDonald, Kathmandu, Nepal.

Sir M MacDonald and Partners Ltd. 1989. Assistance in the establishment of design criteria and manuals for irrigation projects in Nepal, sociological and farmer participation manual. Unpublished draft report, Sir M MacDonald, Kathmandu, Nepal.

Sir M MacDonald and Partners Ltd. 1988. Assistance in the establishment of design criteria and manuals for irrigation projects in Nepal, M.1: general system planning manual. Unpublished draft report, Sir M Macdonald, Kathmandu, Nepal.

Small, Leslie. 1986. Toward a framework for evaluating irrigation performance. Unpublished notes, IIMI, Digana Village, Sri Lanka.

Smith, C.D. 1985. Hydraulic structures. University of Saskatchewan Printing Services, Saskatoon.

Tahal Consulting Engineers Ltd. 1988. Bhairawa Lumbini groundwater irrigation project: updated feasibility study for stage III. Tahal, Tel Aviv.

Tiwari, D.N. 1988. Reconnaissance study of large farmer-managed irrigation systems in Terai belts of Nepal. Unpublished report, International Irrigation Management Institute (IIMI), Kathmandu, Nepal.

Trout, Thomas J. 1982. Diagnosing problems with irrigation conveyance channels, video tape guide number 1. Water Management Synthesis Project, Colorado State University, Fort Collins.

United States Bureau of Reclamation (USBR). 1984. Water measurement manual. USBR, Denver.

Water and Energy Commission Secretariat (WECS). 1985. WECS technical guideline no. 1, the estimation of reference crop evapotranspiration for Nepal's Terai and guidelines for calculating irrigation water requirements. Unpublished report, WECS, Kathmandu, Nepal.

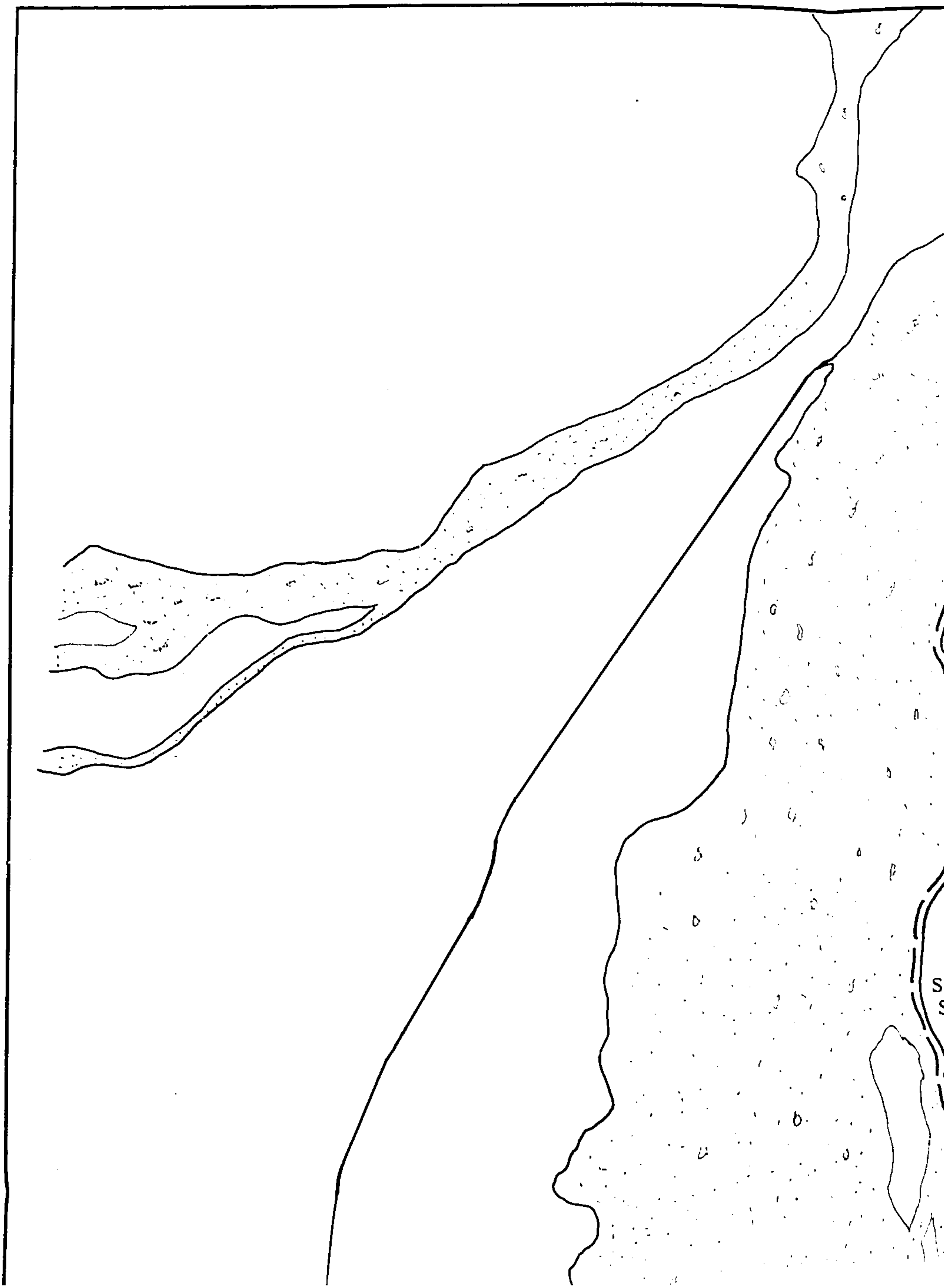
Water and Energy Commission Secretariat (WECS). 1989. Inventory of terai irrigation schemes. Unpublished report, Ministry of Water Resources, Kathmandu.

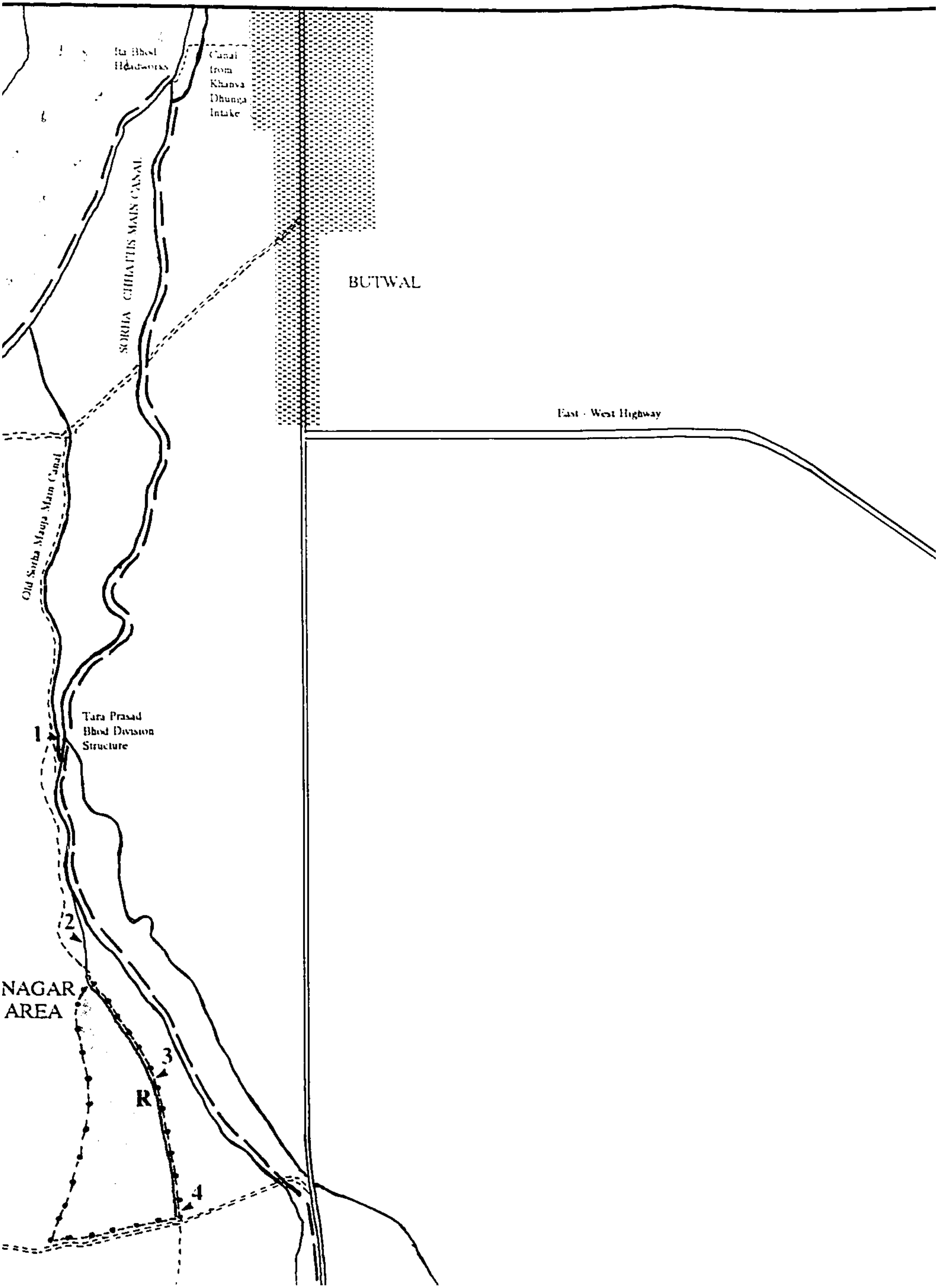
Water Resources and Energy Commission Planning Unit (WEC). 1981. Irrigation sector review. Report No. 3/2/190981/1/1. HMG Nepal, Ministry of Water Resources, Kathmandu.

Weller, J.A. and A.P.E. Green. 1989. Interim report II: water distribution at Porac Gumain river irrigation system, early dry season 1985/86 to late dry season 1987. Hydraulics Research Limited, Wallingford.

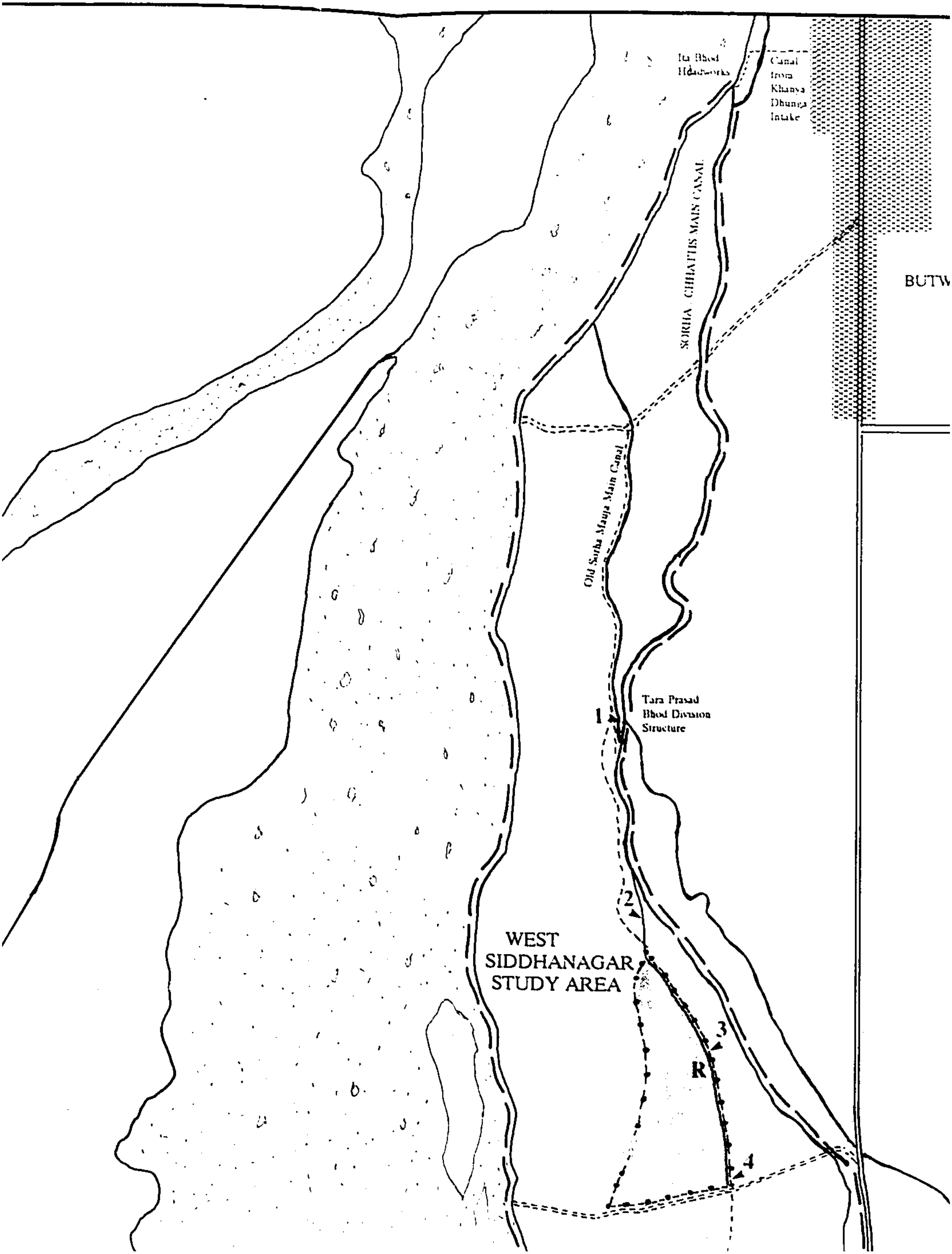
Yoder, R., E. Martin, R. Barker and T. Steenhuis. 1987. Variations in irrigation management intensity: farmer-managed hill irrigation systems in Nepal. WMS Report 67, Water Management Synthesis II Project, Utah State University, Logan, Utah.

Yoder, R. 1986. The performance of farmer-managed irrigation systems in the hills of Nepal. Unpublished dissertation, Cornell University, Isthaca, New York.

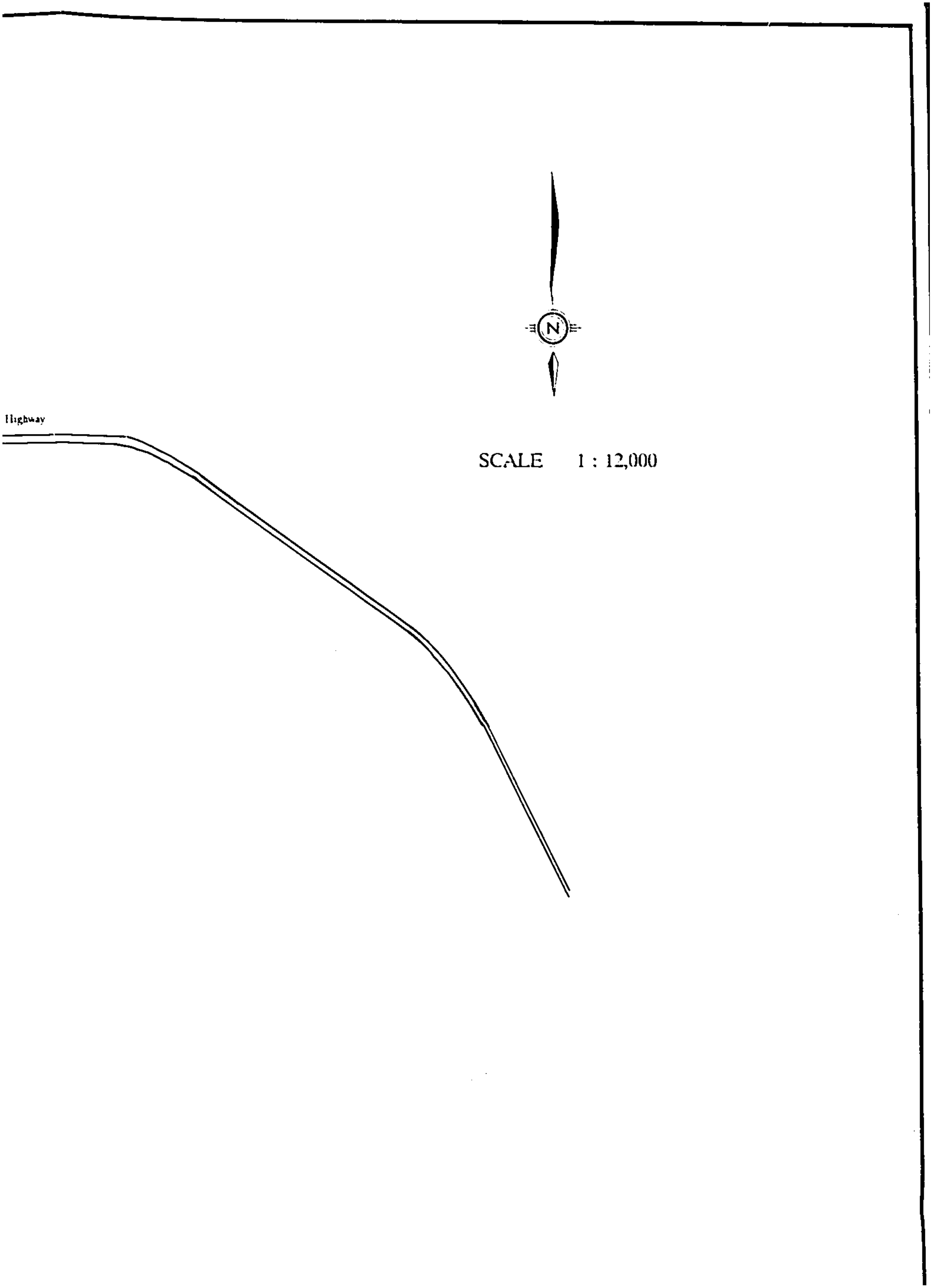




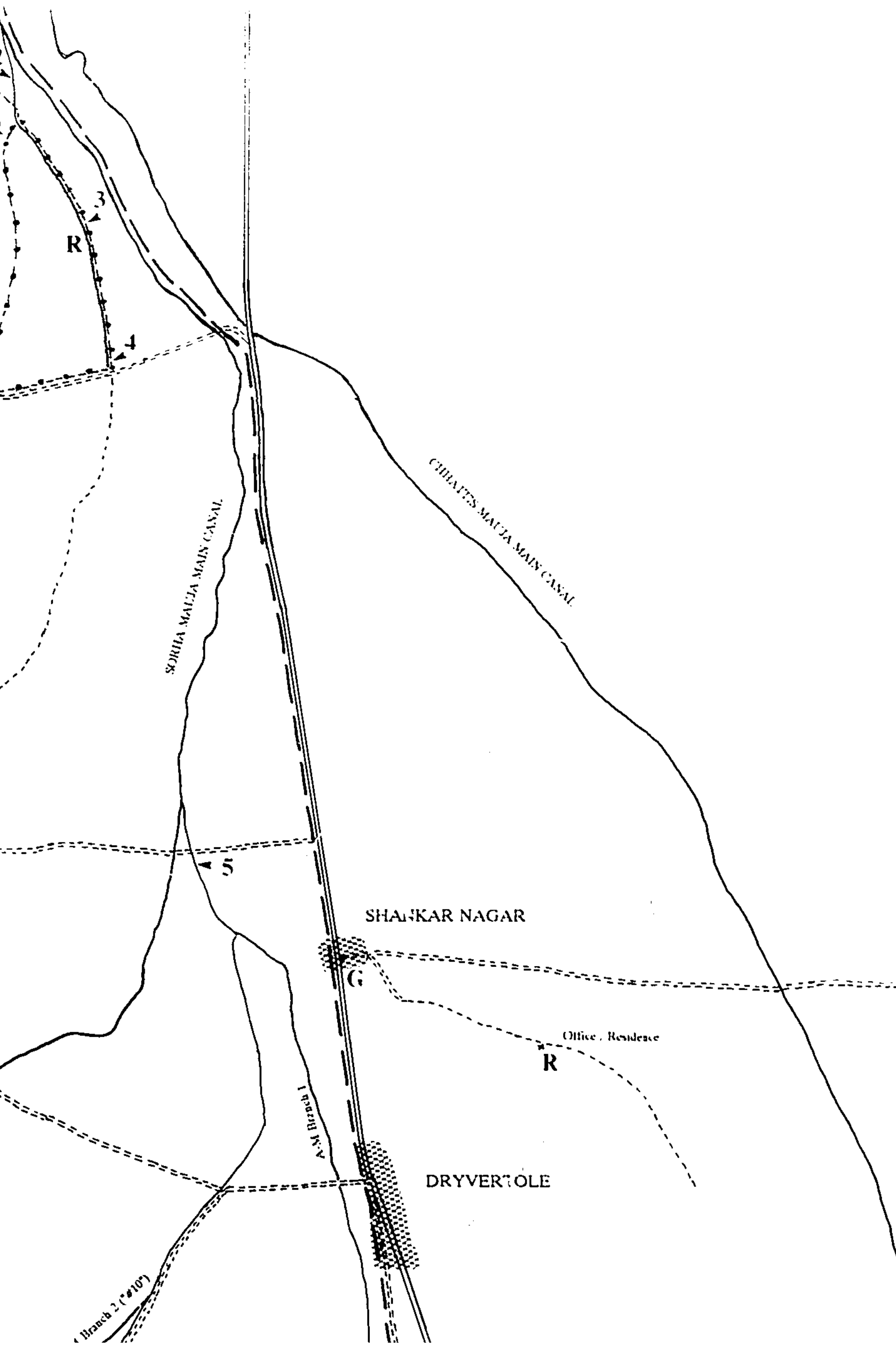
Ita Bhot Headworks
Canal from Khanva Dhunga Intake
SORHA CHHATIS MAIN CANAL
BUTWAL
East - West Highway
Old Sorha Mauja Main Canal
Tara Prasad Bhot Division Structure
1
2
NAGAR AREA
3
R
4



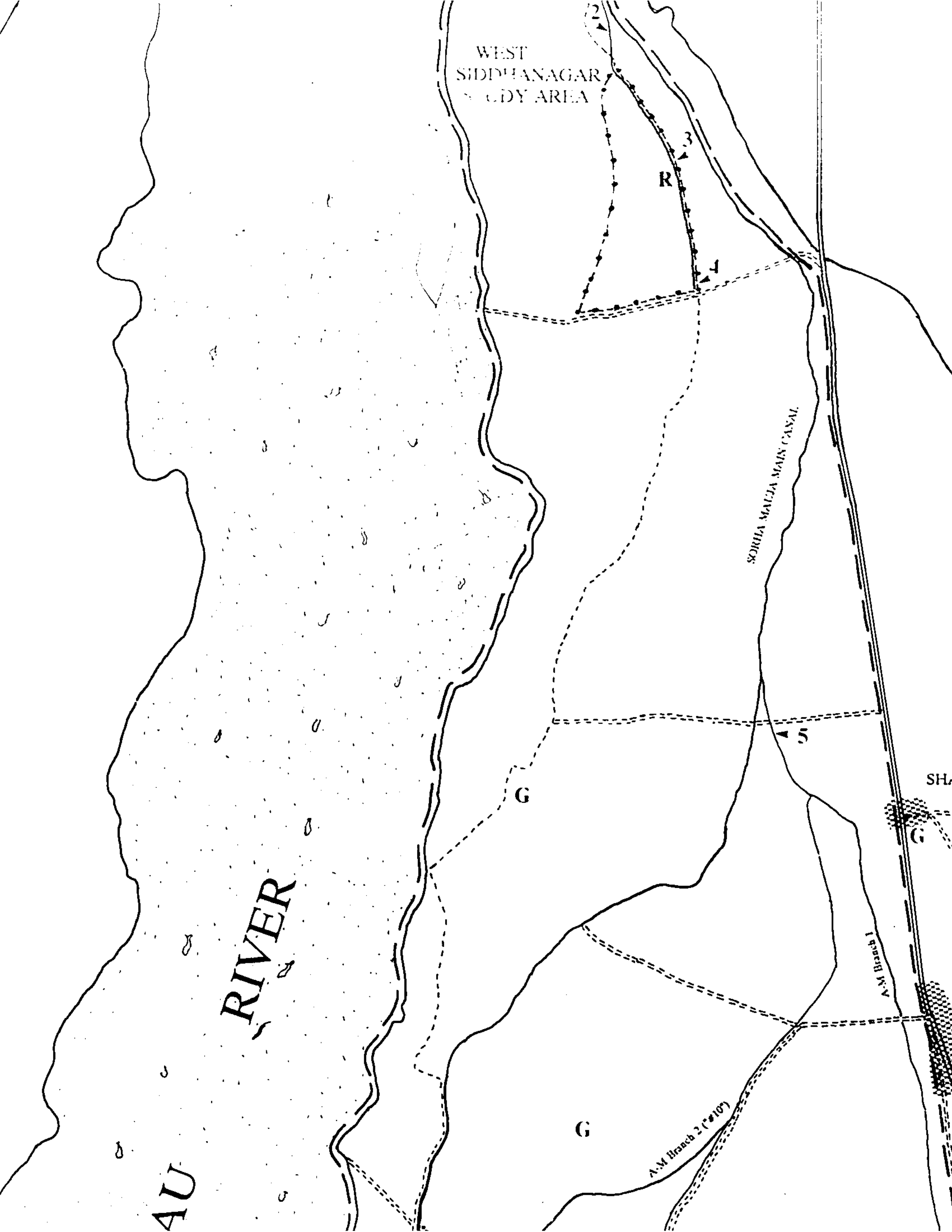
Ita Bhod Headworks
Canal from Khanya Dhunga Intake
SORHA - CHHATTIS MAIN CANAL
BUTW
Old Sorha Mauja Main Canal
Tara Prasad Bhod Division Structure
1
2
3
4
R
WEST SIDDHANAGAR STUDY AREA


Highway
SCALE 1 : 12,000


WEST
SIDDHA
STUDY
Old Indian Canal
RIVER
G



3
R
4
SORHA MAUJA MAIN CANAL
CHHATTS MAUJA MAIN CANAL
5
SHANKAR NAGAR
G
Office / Residence
R
A-M Branch 1
DRYVERTOLE
Branch 2 ("#10")



WEST
SIDDHANAGAR
STUDY AREA
2
3
4
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R
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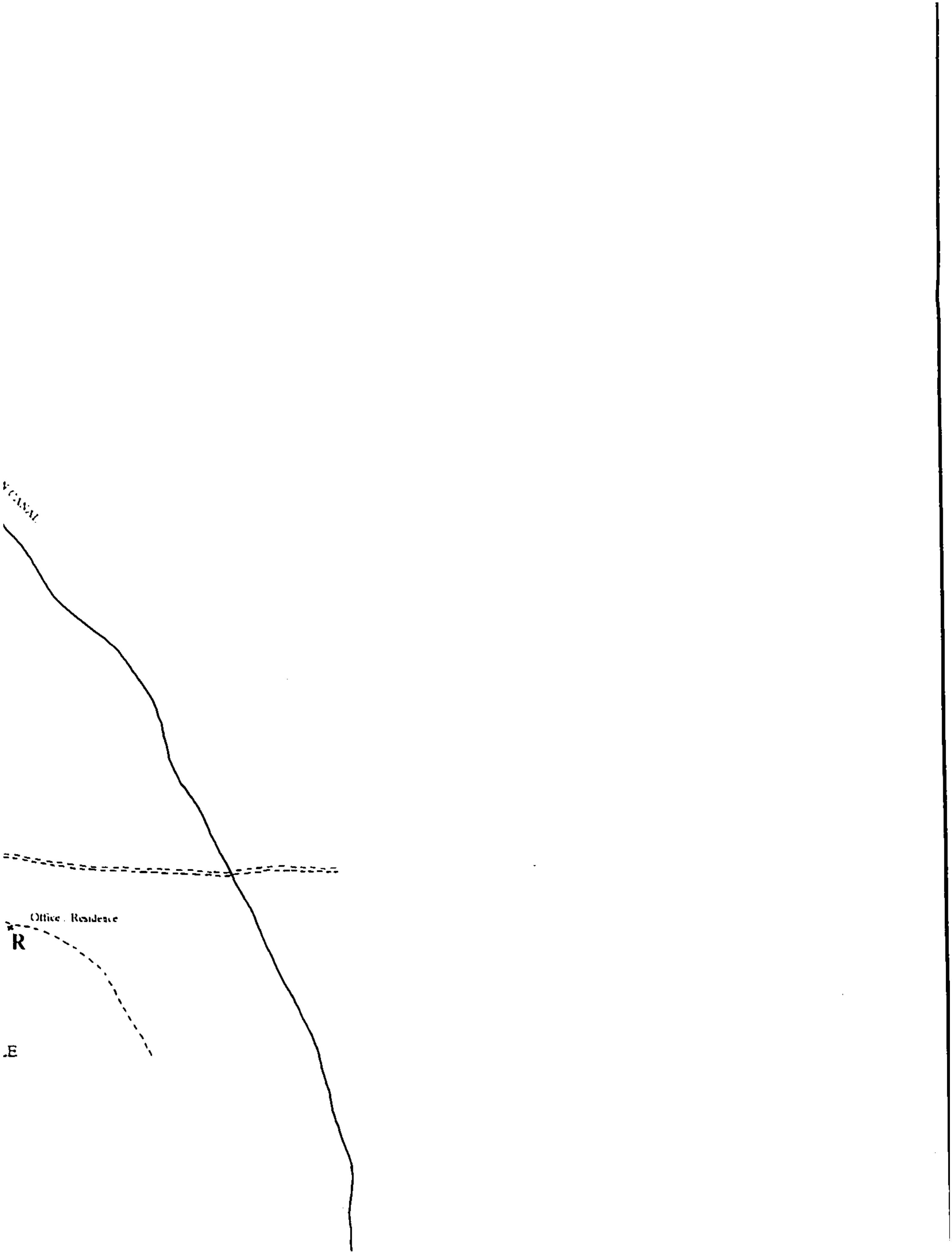
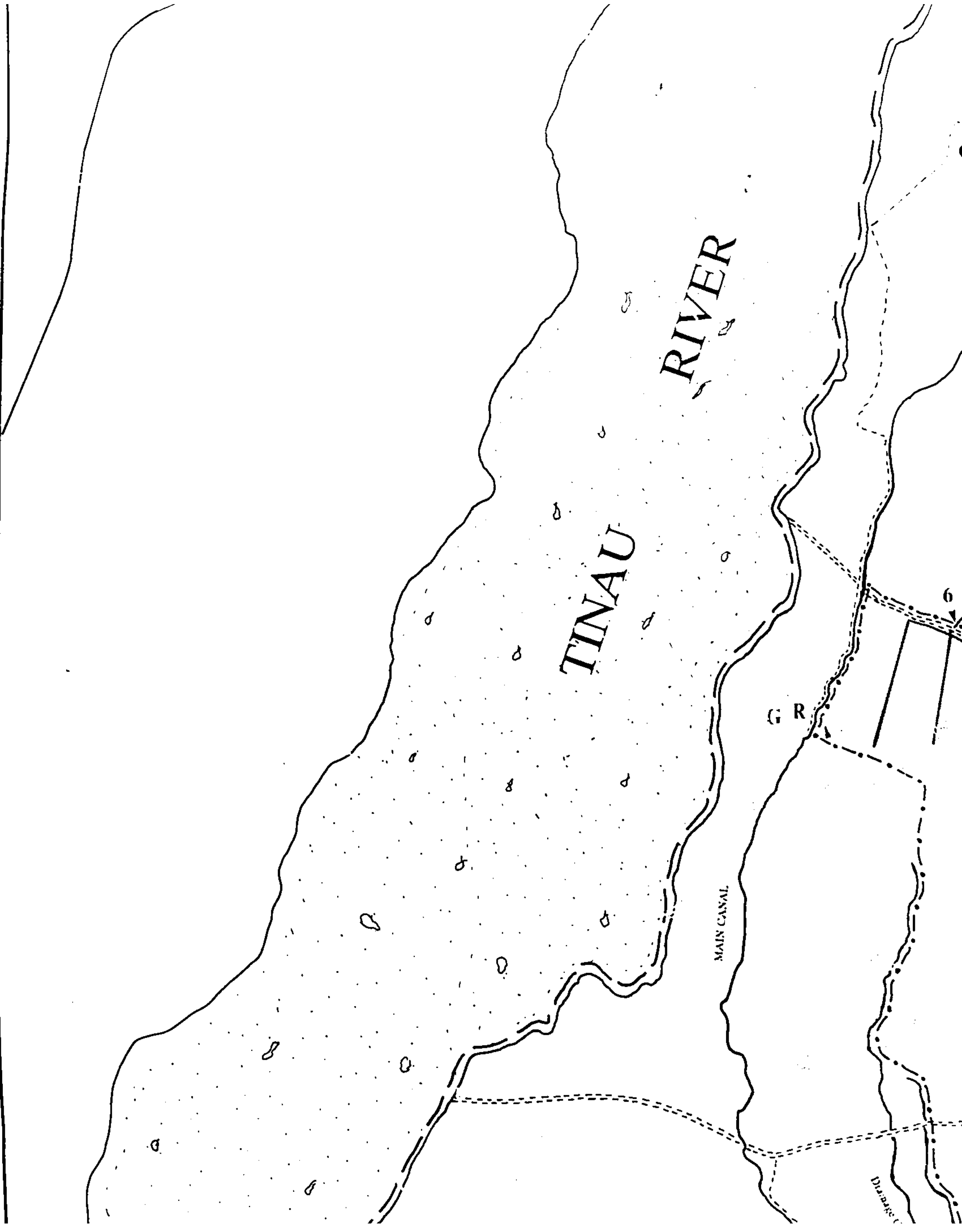
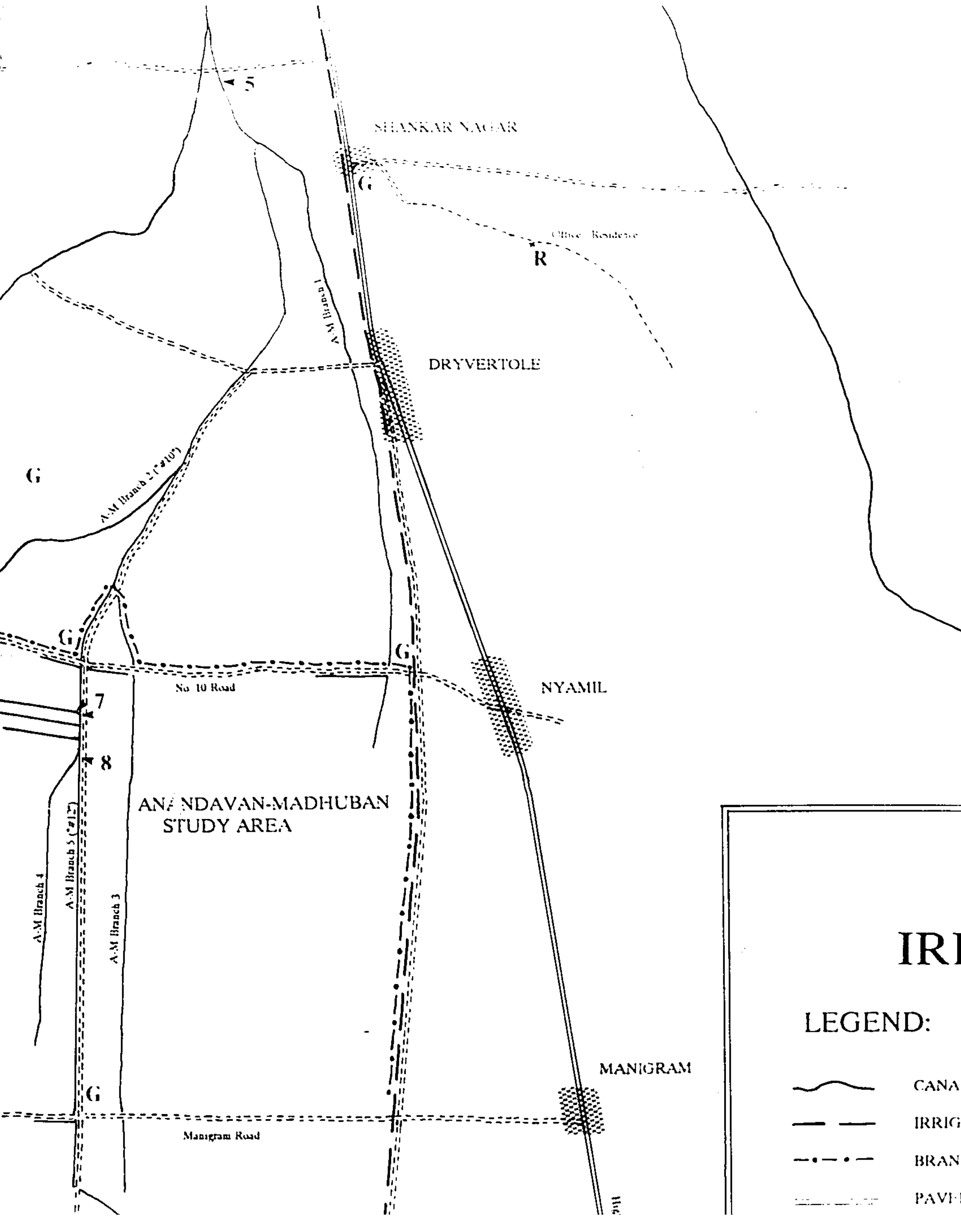
G
SOBHA MAUJA MAIN CANAL
A-M Branch 1
A-M Branch 2 ("#10")
RIVER
AU
SHA

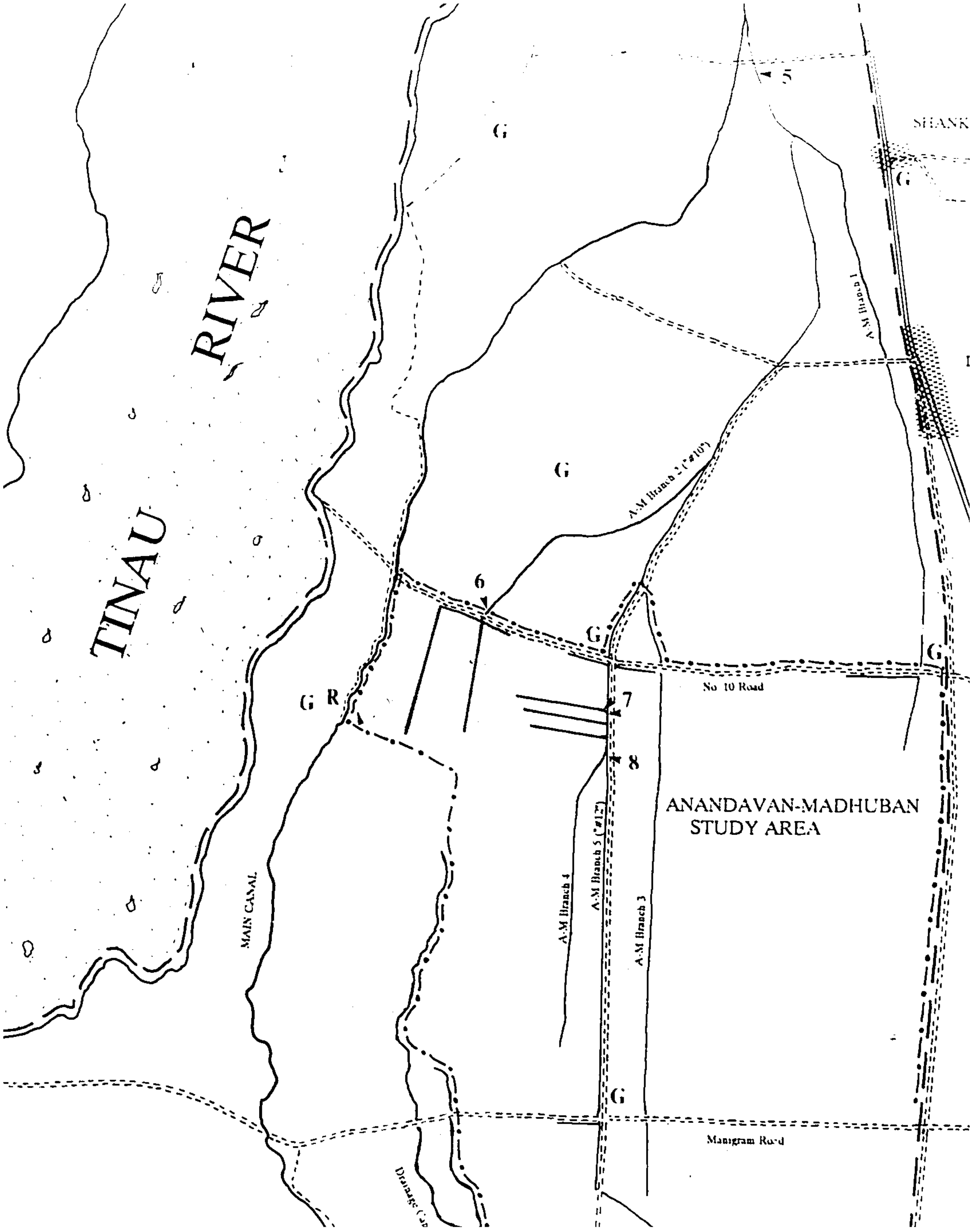


CANAL
Office . Residence
R
E

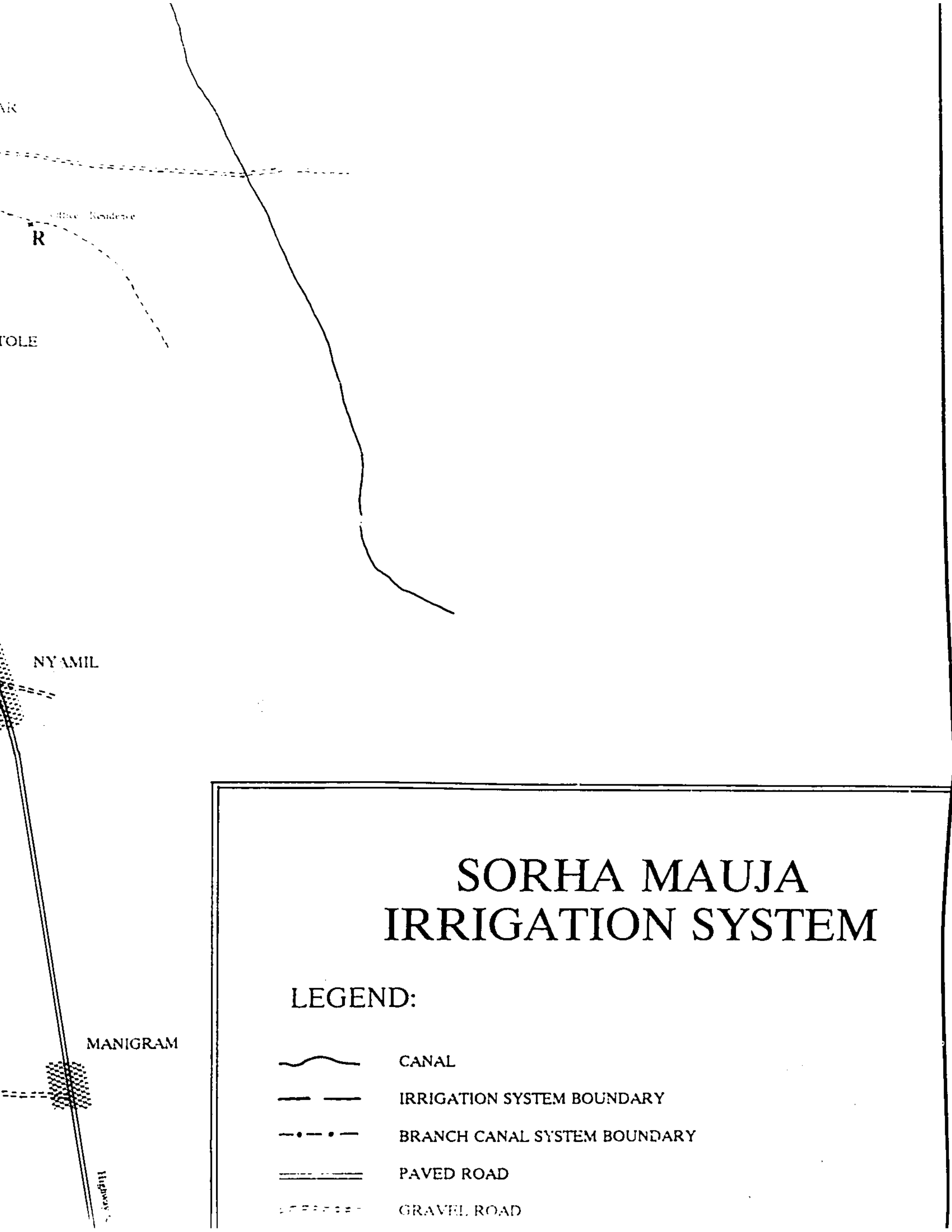


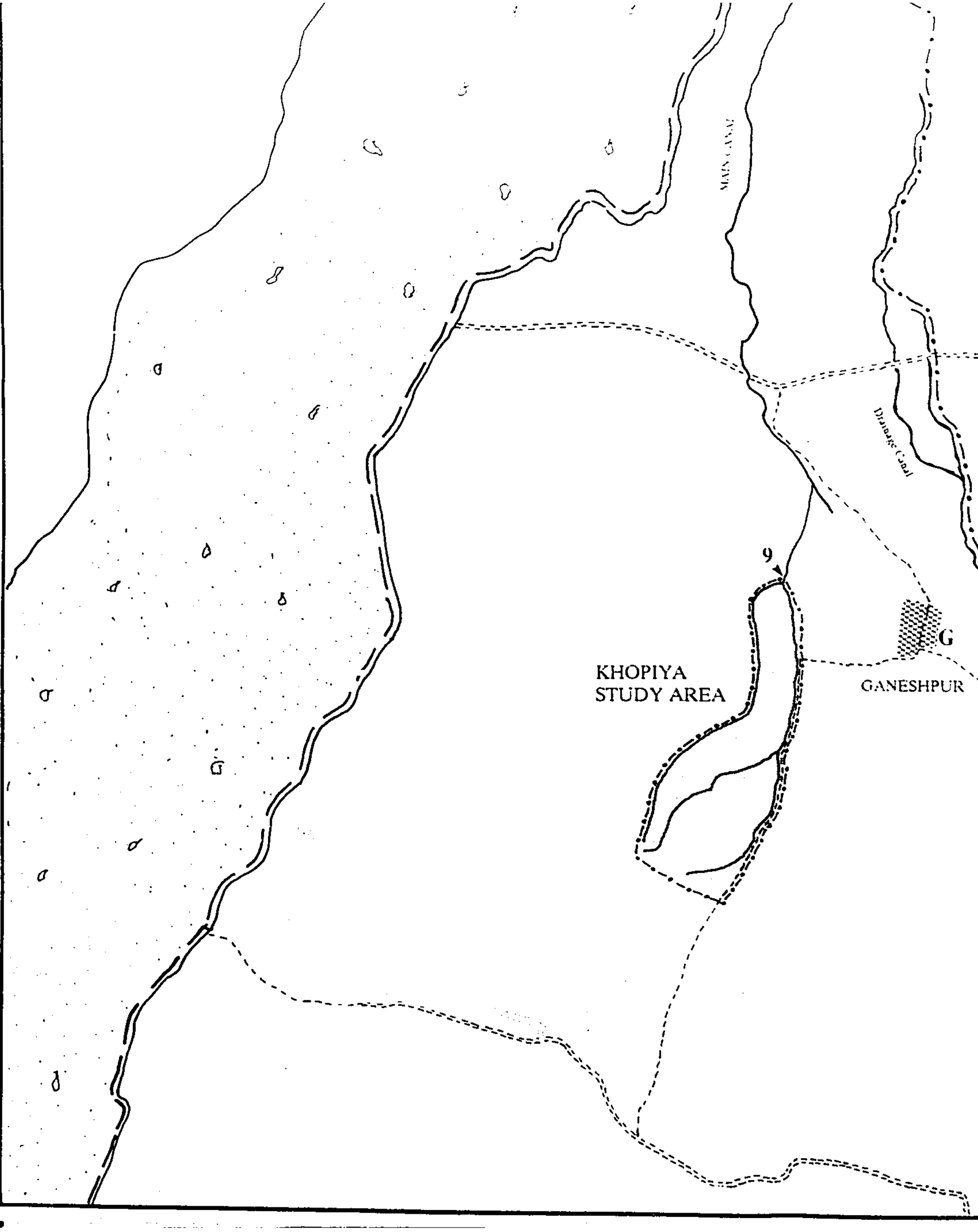
TINAU
RIVER
G R
6
MAIN CANAL

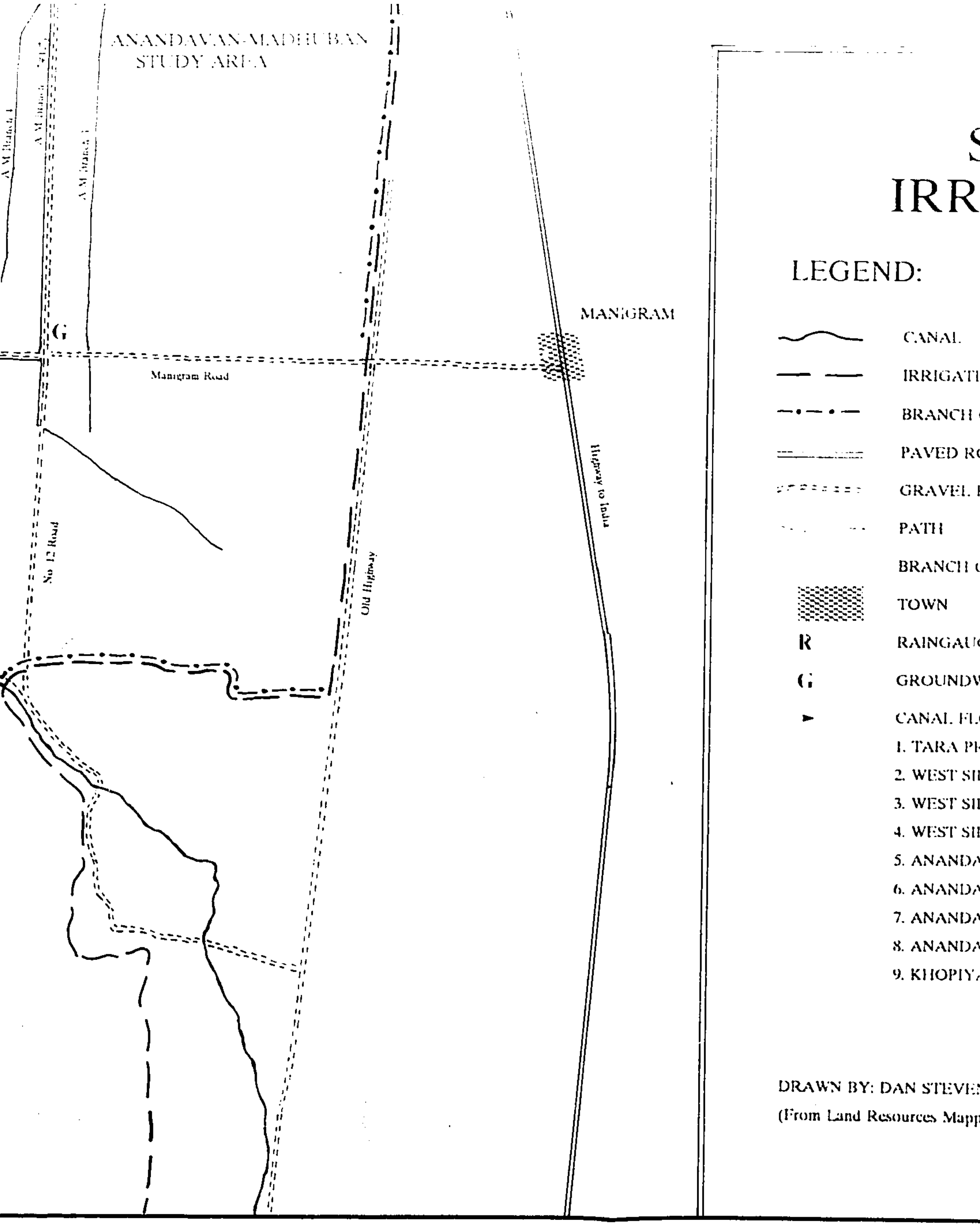

5
SHANKAR NAGAR
G
Office Residence
R
A-M Branch 1
DRYVERTOLE
G
A-M Branch 2 (#10)
G
G
NYAMIL
No 10 Road
7
8
ANANDAVAN-MADHUBAN
STUDY AREA
A-M Branch 4
A-M Branch 5 (#12)
A-M Branch 3
MANIGRAM
G
Manigram Road
LEGEND:



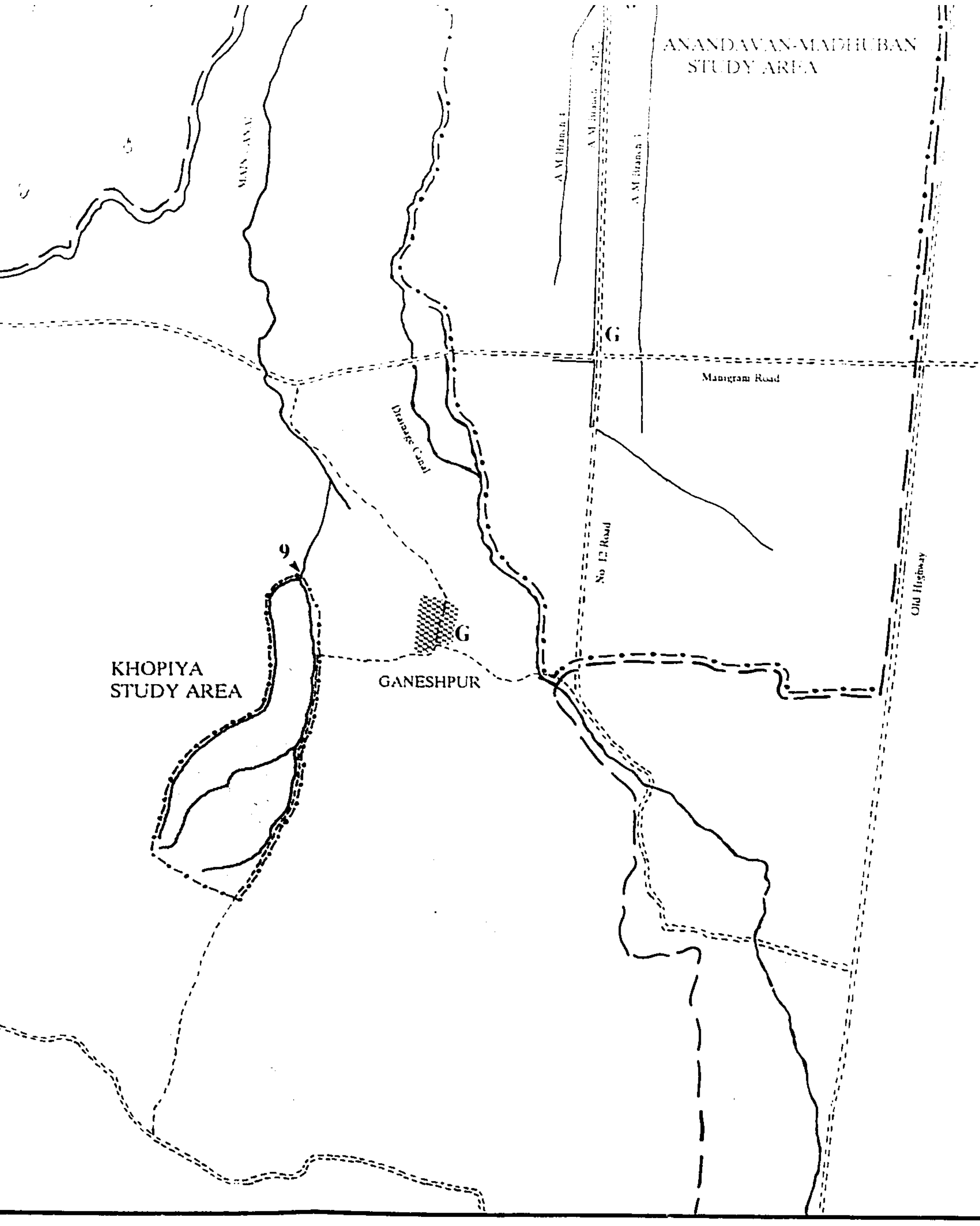
TINAU RIVER
SHANK
G
5
6
7
8
R
A-M Branch 1
A-M Branch 2 ("#10")
A-M Branch 3
A-M Branch 4
A-M Branch 5 ("#12")
MAIN CANAL
No 10 Road
Manigram Road
ANANDAVAN-MADHUBAN
STUDY AREA

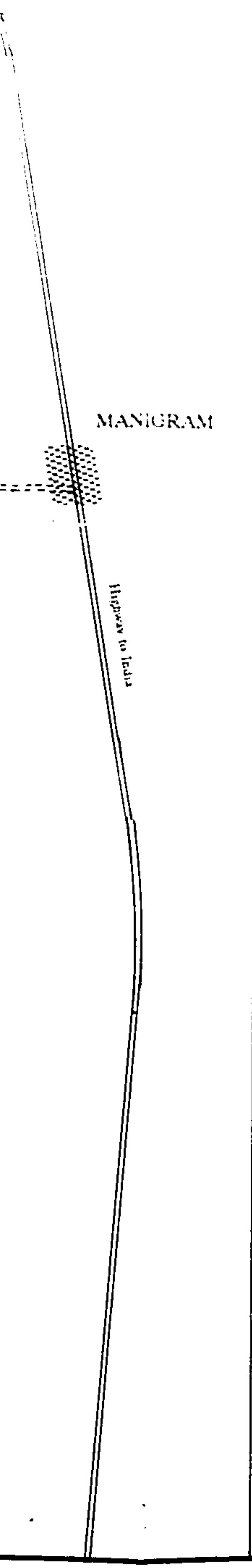

R
TOLE
NYAMIL
MANIGRAM
SORHA MAUJA
IRRIGATION SYSTEM
LEGEND:
CANAL
IRRIGATION SYSTEM BOUNDARY
BRANCH CANAL SYSTEM BOUNDARY
PAVED ROAD
GRAVEL ROAD


MAIN CANAL
Drainage Canal
9
G
KHOPIYA
STUDY AREA
GANESHPUR



ANANDAVAN-MADHUBAN
STUDY AREA
A M Branch
MANIGRAM
G
Manigram Road
Highway to India
No 12 Road
Old Highway
S
IRR
LEGEND:
CANAL
IRRIGATI
BRANCH
PAVED RO
GRAVEL
PATH
BRANCH
TOWN
R
RAINGAU
G
GROUNDW
CANAL FL
1. TARA P
2. WEST SI
3. WEST SI
4. WEST SI
5. ANANDA
6. ANANDA
7. ANANDA
8. ANANDA
9. KHOPIYA
DRAWN BY: DAN STEVE
(From Land Resources Mapp


ANANDAVAN-MADHUBAN
STUDY AREA
G
Manigram Road
Drainage Canal
No 12 Road
Old Highway
9
G
KHOPIYA
STUDY AREA
GANESHPUR



SORHA MAUJA IRRIGATION SYSTEM

LEGEND:

CANAL

IRRIGATION SYSTEM BOUNDARY

BRANCH CANAL SYSTEM BOUNDARY

PAVED ROAD

GRAVEL ROAD

PATH

BRANCH CANAL STUDY AREA

TOWN

R RAINGAUGE

G GROUNDWATER MONITORING WELL

► CANAL FLOW MONITORING STATION:

1. TARA PRASAD BHOD (SORHA-CHHATTIS) DIVISION STRUCTURE
2. WEST SIDDHANAGAR BRANCH - INLET
3. WEST SIDDHANAGAR BRANCH - MIDDLE
4. WEST SIDDHANAGAR BRANCH - DRAINAGE
5. ANANDAVAN-MADHUBAN BRANCH - INLET
6. ANANDAVAN-MADHUBAN SUB-BRANCH - "#10"
7. ANANDAVAN-MADHUBAN FARM DITCH - "7 BIGHA"
8. ANANDAVAN-MADHUBAN SUB-BRANCH - "#12"
9. KHOPIYA BRANCH - INLET

DRAWN BY: DAN STEVENS, JULY 1990

(From Land Resources Mapping Project Air Photos, 1978)