PN-AAZ-904
56264

Diagnostic Analysis of Four Irrigation Schemes in Polonnaruwa District, Sri Lanka: Interdisciplinary Report

Water Management Synthesis Project
WMS Report 61

DIAGNOSTIC ANALYSIS OF FOUR IRRIGATION SCHEMES IN POLONNARUWA DISTRICT, SRI LANKA: INTERDISCIPLINARY REPORT

Prepared by

L.J. Nelson, M.K. Kilkelly, Siri Hettige, M.A.W. Bandaranayake, J.W.D. Somasundra, K.A.V.S. Imbulana, I. de Silva, R.A. Mohammed, and W.R. Laitos

Editors: D. Fowler and M.K. Kilkelly

WMS Report 61

Prepared in cooperation with the United States Agency for International Development, Contract DAN-4127-C-00-2086-00.
All reported opinions, conclusions or recommendations are those of the author (contractor) and not those of the funding agency or the United States Government. Mention of commercial products in this publication is solely to provide information. It does not constitute endorsement by USAID over other products not mentioned.

WATER MANAGEMENT SYNTHESIS II PROJECT
University Services Center
Colorado State University
Fort Collins, CO 80523

in cooperation with the
Consortium for International Development

March 1988

TABLE OF CONTENTS

Section		Page
	ACKNOWLEDGMENTS	v
I.	INTRODUCTION	1
	A. The Diagnostic Analysis Project	1
	B. About this Report	3
	C. Background and Description of the Irrigation Schemes.	4
II.	INVESTIGATIVE APPROACH	7
	A. Components of the Diagnostic Analysis	7
	1. Main system engineering	7
	2. On-farm engineering	8
	3. Agronomy	9
	4. Economics	9
	5. Sociology	9
	6. Women in development	10
	B. Sampling Procedures	10
	C. WMSII Supporting Studies	14
III.	INTERDISCIPLINARY FINDINGS	16
	A. Water Control	16
	1. Measurements and observations concerning water control	16
	2. Factors affecting water control	22
	3. The effects of inadequate water control	26
	B. Agricultural Productivity	29
	1. Measurements and observations concerning productivity	29
	2. Factors affecting productivity	31
	3. Effects of reduced agricultural productivity	34
	C. Resource Conservation	37
	1. Land use patterns	37
	2. Soils	39
	3. Water quality	40
	D. Farmer Involvement	41
	1. *Yala* irrigation schedule	41
	2. Operation and maintenance	41
	3. Project committee system	43
IV.	SUMMARY OF FINDINGS AND RECOMMENDATIONS	45
	A. Summary of Findings	45
	1. Water control	45
	2. Agricultural productivity	46

TABLE OF CONTENTS (continued)

Section	Page
3. Resource conservation	48
4. Farmer involvement	49
B. Recommendations	50
1. Water control	50
2. Agricultural production	52
3. Additional institutional involvement	54
V. LITERATURE CITED	55
VI. GLOSSARY OF ABBREVIATIONS AND TERMS	56

ACKNOWLEDGMENTS

The diagnostic analysis of Parakrama Samudra, Giritale, Minneriya, and Kaudulla irrigation schemes was sponsored by the United States Agency for International Development, Colombo Mission, Sri Lanka, and by the Irrigation Management Division of the Ministry of Lands and Land Development, Sri Lanka. The project also received considerable training, technical assistance, and report preparation support from USAID's Water Management Synthesis II Project. The support provided by these three organizations was greatly appreciated, especially the efforts of Dr. Herb Blank and Mr. Joe Alwis. In addition, the authors of this report would like to thank the Irrigation Department in Colombo for the office and logistic support provided during the investigations.

Special recognition should also be given to the various government agencies in the Polonnaruwa District. In particular, the efforts of the government agent, Mr. U.G. Jayasinghe, and the additional government agent of development, Mr. Palitha Elkaduwa, in coordinating the participation of district government officers in the investigations and in providing office support and transport during the investigations were greatly appreciated.

The efforts of Mr. Linton Wijesuriya and Mr. Piyaddassa, former and current Deputy Director of Irrigation, respectively, for the Polonnaruwa District, in providing administrative, logistic, and technical support to the investigations were invaluable. Appreciation is also extended to the Department of Irrigation, the Department of Agriculture, the Department of Statistics, the Agricultural Development Authority, the Agrarian Services Department, the Land Commissioners Department, the Ministry of Plan Implementation, and the Rural Development Office for releasing field investigators from their regular duties to participate in the investigations.

The authors of this report also extend their gratitude to all team leaders, technical consultants, and field investigators who participated in data collection, analysis, and discipline report preparation for the four irrigation schemes. Above all, the authors of this report express their gratitude to the farm families of the four irrigation schemes, who willingly contributed their knowledge and time to the investigations.

Larry J. Nelson
Coordinator of the
Diagnostic Analysis Project

I. INTRODUCTION

A. THE DIAGNOSTIC ANALYSIS PROJECT

In Sri Lanka, the development of new irrigation schemes and the improvement and rehabilitation of old schemes are prime targets of agricultural planning. Large irrigation schemes associated with resettlement projects have been constructed to extend and increase the agricultural productivity of Sri Lanka's Dry Zone. However, the operation of many of the schemes has been less than optimal, and the anticipated results have not always been realized. Consequently, new institutional policies and programs emphasize alternative strategies for improving the productivity and performance of irrigation systems.

One such plan by the Government of Sri Lanka involved creating the Irrigation Management Division (IMD) within the Ministry of Lands and Land Development (MLLD). In addition to other responsibilities, the IMD is expected to establish a system for monitoring and evaluating the performance of irrigation schemes. These monitoring and evaluation methods will be based on diagnostic analysis procedures developed by the Water Management Synthesis Project (1983) at Colorado State University.

Diagnostic analysis techniques were introduced to Sri Lanka through three in-country, professional development workshops conducted in 1982, 1983, and 1984. Fundamental to diagnostic analysis is the philosophy that irrigation problems are not confined to one single discipline such as engineering or agronomy, but rather, that they involve a wide range of issues that include social and economic aspects as well. As part of the training workshops, interdisciplinary teams of participants investigated an existing irrigation scheme, identified constraints, and discussed various approaches to solving irrigation-related problems.

Reports from these workshops were written on the Rajangana Irrigation Scheme (1982) and System H of the Mahaweli (1982, 1983). Although these reports were limited in scope due to the nature of the training workshop, they provided useful information and valuable insights into the operation of the irrigation systems studied. As a result, the MLLD recognized the benefits of this investigative approach and desired to employ these concepts as a practical, preliminary approach to identifying constraints in irrigation systems.

An opportunity to use diagnostic analysis as a tool for gathering baseline information arose with the creation of the Irrigation Systems Management (ISM) Project. The ISM Project, funded by the United States Agency for International Development (USAID), proposes to rehabilitate and improve four irrigation schemes in the Polonnaruwa District of Sri Lanka: Parakrama Samudra, Giritale, Minneriya, and Kaudulla (Figure 1).

This baseline data collection effort was called the Diagnostic Analysis Project. Diagnostic analysis was considered the most appro-

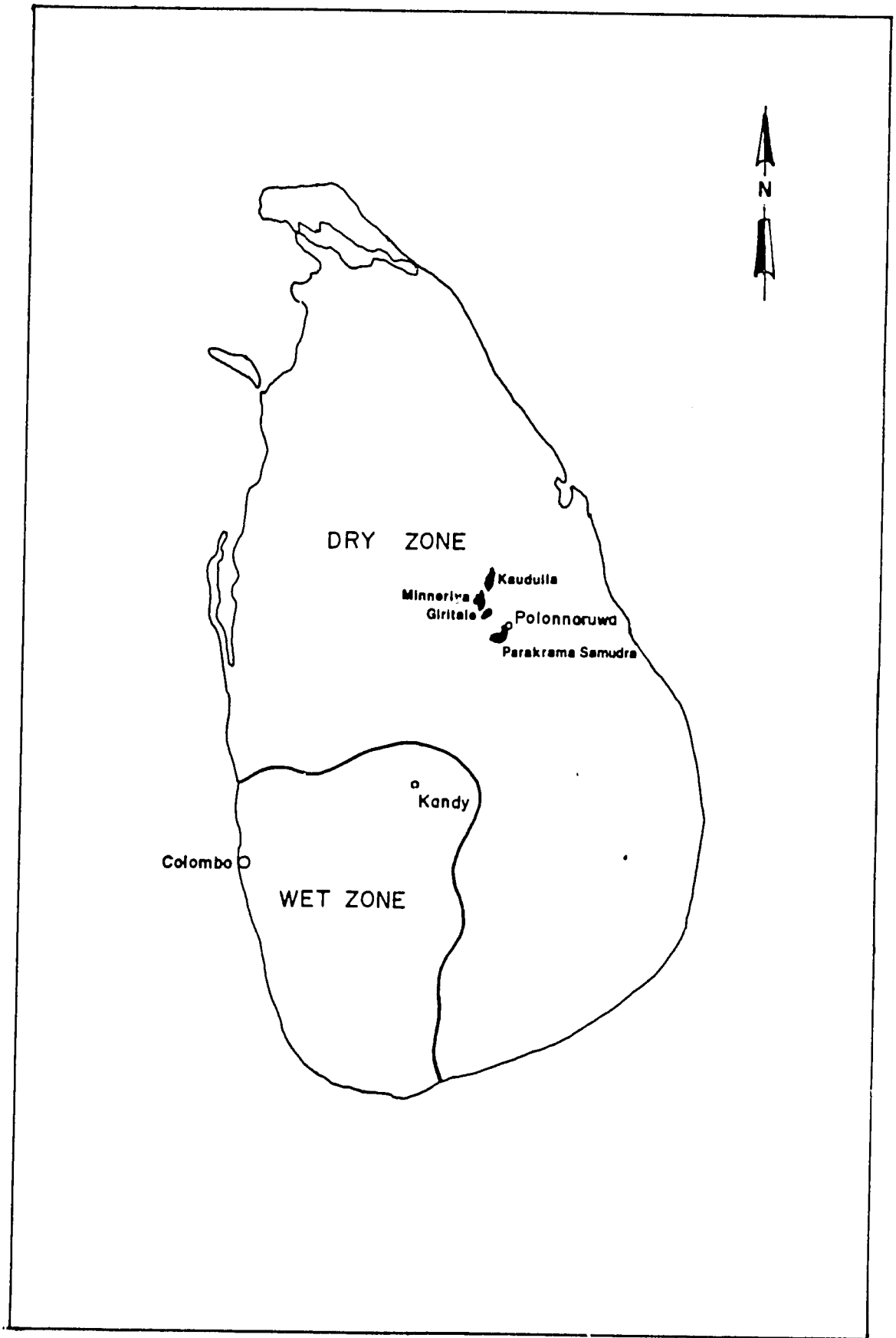

Figure 1. Map of Sri Lanka showing the location of Parakrama Samudra, Giritale, Minneriya, and Kaudulla tanks.

priate investigatory method to use; although physical improvements to the existing irrigation schemes were important considerations, various socio-economic efforts were also included in the ISM Project design (Skogerboe et al., 1984).

In effect, the Diagnostic Analysis Project was designed to provide a better understanding of these irrigation schemes in order to assist the ISM Project in determining pragmatic, cost-effective means for improving the operation of these systems. The collection of a reliable, extensive volume of data would provide valuable information concerning system operation. In addition, for evaluation purposes, this information could later be compared to information gathered after the irrigation schemes are rehabilitated and improved.

The overall objectives of the Diagnostic Analysis Project were:

1. To strengthen the IMD's institutional capacity and the abilities of its associated personnel to use diagnostic analysis techniques to study existing irrigation schemes.

2. To assist in establishing a set of evaluation procedures and methodologies for continual monitoring of irrigation system operations.

3. To provide detailed background information on the selected irrigation schemes for future use in rehabilitation and improvement projects.

B. ABOUT THIS REPORT

The following report synthesizes the reports produced by the various disciplinary teams (main-system engineering, on-farm engineering, agronomy, economics, sociology, and women in development) for the four irrigation schemes studied (Parakrama Samudra, Giritale, Minneriya, and Kaudulla). The diagnostic analysis studies were conducted on Parakrama Samudra and Giritale schemes during 1985 yala, and on Kaudulla and Minneriya schemes during 1986 yala. Although most of the findings in the system reports are based on data collected only during these periods, on occasion, supplementary information for data collected during 1985-86 maha may be included for Parakrama Samudra and Giritale schemes.

To produce this report, interdisciplinary outlines were initially developed from each of the four irrigation scheme reports. Because many of the overall observations and conclusions were similar for the different irrigation systems, an attempt was made to integrate the findings from the four irrigation schemes into one interdisciplinary report. Therefore, unless a specific reference is made to a particular irrigation scheme, the finding applies to all four of the irrigation schemes studied.

The extensive data produced by the Diagnostic Analysis Project is contained in the separate scheme reports.[1] This interdisciplinary report is limited to major observations and findings. If the reader requires more detailed information or discussion on a particular discipline or system, we recommend referring to the scheme reports.

Due to various logistical problems involved in implementing a study of this scope, precise replication and coordination among disciplines for all irrigation schemes was not achieved. Therefore, information may be incomplete for some subjects, disciplines, or irrigation schemes.

C. BACKGROUND AND DESCRIPTION OF THE IRRIGATION SCHEMES

The Polonnaruwa District has long been considered an example of remarkable engineering and agricultural achievement. As early as the 3rd century, A.D., extensive areas of land were cultivated by irrigation systems designed and built by a technologically advanced ancient civilization. After falling into disrepair, many of these systems were expanded and restored in the 12th century, A.D., only to be abandoned with the collapse of the civilization.

Not until about 1930 were restoration attempts begun on the reservoirs to return the Polonnaruwa District to its former productivity. The restoration of these irrigation systems was closely associated with a series of government resettlement and colonization projects started in the 1940s and continuing through the 1970s.

These resettlement and colonization projects were attempts by the Government of Sri Lanka to relieve population pressures in the Wet Zone, and to simultaneously increase the overall agricultural production of Sri Lanka. Table 1 presents some background information about the four irrigation schemes studied under the Diagnostic Analysis Project.

After the most recent restoration, the tanks obtained access to water from the Mahaweli Development Project, a massive scheme of large storage reservoirs and river diversion facilities now nearing completion.

---

[1]Fowler, D. and M.K. Kilkelly (eds.). 1987. Diagnostic analysis of Parakrama Samudra Scheme, Sri Lanka: 1985 yala discipline reports. WMS Report 57. Water Management Synthesis II Project, Colorado State University, Fort Collins.

Fowler, D. and M.K. Kilkelly (eds.). 1987. Diagnostic analysis of Giritale Scheme, Sri Lanka: 1985 yala discipline reports. WMS Report 58. Water Management Synthesis II Project, Colorado State University, Fort Collins.

Fowler, D. and M.K. Kilkelly (eds.). 1987. Diagnostic analysis of Minneriya Scheme, Sri Lanka: 1986 yala discipline reports. WMS Report 59. Water Management Synthesis II Project, Colorado State University, Fort Collins.

Fowler, D. and M.K. Kilkelly (eds.). 1987. Diagnostic analysis of Kaudulla Scheme, Sri Lanka: 1986 yala discipline reports. WMS Report 60. Water Management Synthesis II Project, Colorado State University, Fort Collins.

Access to Mahaweli water provided not only a supplement to the storage of maha rainfall, but ensured a more reliable year-round source of water for irrigation. In addition, the return flows from the irrigation systems discharge into small drains and river channels that eventually flow into other parts of the Mahaweli River.

The four irrigation schemes are interconnected through a complex system of diversions and return flows. Therefore, the operation and management of the four schemes requires that decisions concerning one scheme be evaluated for their potential effect on the other schemes.

All four irrigation schemes are located in the Polonnaruwa District of the North Central Province of Sri Lanka (Figure 1) and are characterized as gently undulating Dry Zone, with elevations ranging from 45-456 ft above sea level. The average annual rainfall is 58 inches, which falls predominantly during maha (the wet season; October to March). There is no rainfed paddy cultivation during yala (the dry season; April to September), but a limited extent of rainfed paddy cultivation may occur during maha. In each of the four irrigation schemes, paddy is the primary crop cultivated, with variable amounts of subsidiary crops such as chili, tobacco, maize, soybean, cowpea, groundnut, sesame, onions, and other vegetables grown in yala, when water for field irrigation may be limited.

Table 1. Background information about the four irrigation systems chosen for study by the Diagnostic Analysis Project.

	PSS	Giritale	Minneriya	Kaudulla
Date of Settlement	1942	1956	1930-1950	1950-1976
Designed Command (ac)	19,632	6,193	16,739	10,500
Present Command (ac)*	24,371	7,105	20,914	13,300**
Lowland Allotment (ac)	5	3	St I-III 5 St IV 3	St I 3 St II 2
Highland Allotment (ac)	3	1	St I-III 3 St IV 2	St I 2 St II 1
Original no. Allottees	4,000	1,500	2,200	4,000

*Based on acreage figures of Martin, 1988.
**Aerial photo map incomplete, therefore this figure is based on available estimates.

The Polonnaruwa District has been referred to as the "rice bowl" of Sri Lanka as it has some of the highest yields for paddy throughout the island. Average yala paddy yields from 1969 to 1985 were 86.1 bu/ac (Polonnaruwa Kachcheri records). The use of short-season, high yielding varieties is fairly widespread.

The highland allotments generally are not well utilized due to inadequate water. Even so, most families maintain perennial trees such as coconut, banana, or jackfruit. During maha, small gardens containing a diverse mixture of vegetables are planted, but yields remain low.

In the four decades since the major tanks were restored, in-migration created by the resettlement programs, and natural increases, have swelled population figures for the area considerably. The 1971 population total for the Polonnaruwa District was recorded at 163,700. In 1981 the total reported was 262,800. Figures from the Department of Census and Statistics, Central Bank of Ceylon, showed a total 1984 population figure for the Polonnaruwa District of over 284,000 people. This represents approximately 1.8 percent of the total national population, with a density rate of 83 persons/km^2.

The most recent growth rate figure, reported for 1983-84, was 2.2 percent, well above the national average of 1.2 percent. This population growth factor, in combination with unemployment and underemployment, has led to a concentration of low income groups in the rural agricultural sector. The difficulty of absorbing a growing labor force when few alternatives to agriculture are available is considered a serious problem in the district.

Data from the 1981 census reported a district population composed of Sinhalese (90.9 percent), Tamil (2.2 percent), Indian Tamil (0.1 percent), Moor (6.5 percent), Burgher (less than 0.1 percent), Malay (0.1 percent), and other (0.2 percent).

II. INVESTIGATIVE APPROACH

Baseline investigations of Parakrama Samudra and Giritale irrigation schemes during 1985 yala, and of Minneriya and Kaudulla irrigation schemes during 1986 yala, were conducted using diagnostic analysis. Diagnostic analysis is an investigative method that examines the irrigation scheme as it actually operates, not as it is assumed to operate. It is set apart from other investigative methods in that it involves a systems perspective, uses an interdisciplinary approach, and acknowledges the need for the involvement of the farm family.

Basic to diagnostic analysis is the understanding that surface irrigation systems such as those studied in Polonnaruwa District are complex. The systems perspective permits an arbitrary subdivision of the irrigation scheme into a set of diverse, but related, systems. Each system possesses certain physical, biological, social, and economic performance parameters that are more easily defined and evaluated by an interdisciplinary team of engineers, agronomists, sociologists, and economists, than by any one of these disciplines alone.

In this case, the four irrigation schemes were subdivided into four systems (physical, irrigated cropping, economic, and social-organizational) which correspond to the specialized skills of a team of professionals in the areas of engineering, agronomy, economics, and sociology. For practical reasons, the physical system was further subdivided into the water delivery subsystem and the water application subsystem. This subdivision ensured that water deliveries were evaluated from the sluice gate of the tank to the farmers' fields. In addition, a component relating specifically to women in development was included as part of the larger, interdisciplinary investigations. The women in development investigators were responsible for documenting the participation of women in irrigated agricultural production. In the following sections, the performance parameters and variables that were evaluated in each investigative component of the diagnostic analysis are summarized.

A. COMPONENTS OF THE DIAGNOSTIC ANALYSIS

1. Main System Engineering

The main system engineering investigators were responsible for evaluating the performance of the water delivery subsystem. The water delivery subsystem was defined as the network of canals that deliver water from the sluice gate of the tank to the field channel turnouts. The primary objective of this subsystem is to provide the water control necessary to ensure successful production of irrigated agricultural crops. A second objective of this subsystem is to provide water for domestic use, either directly from the channels or indirectly through subsurface recharge of the homestead wells on the highland allotments.

Three performance parameters were used to evaluate the ability of this subsystem to provide the water control necessary to assure proper

distribution of water throughout the irrigated command area. The first performance parameter, adequacy, described the ability of the subsystem to supply the quantity of water necessary to meet crop water requirements. Adequacy of water deliveries was evaluated by comparing the designed water supply or the estimated crop water requirements (evapotranspiration + deep percolation) with the actual depth of water delivered to the command area during periods of peak water use and throughout the irrigation season.

The second performance parameter, equity, described the ability of the subsystem to distribute an adequate water supply to all users on the system. Equity of water deliveries were evaluated by comparing the designed water supply or the estimated crop water requirements with the actual depth of water delivered to subcommand units during periods of peak water use and throughout the irrigation season.

The third performance parameter, reliability, described the ability of the subsystem to distribute water to users on an agreed-upon schedule (rotation). Reliability of water deliveries were evaluated by examining temporal variations in rotation and flow rates.

Physical data used to evaluate the three performance parameters included daily flow measurements at selected supply points throughout the water distribution subsystem, subcommand acreages (D-channel and F-channel) and total command acreages for each scheme, and climatic data for estimating evapotranspiration. In addition, longitudinal and cross-sectional profile surveys of selected sections of the canals and observational information on the condition and function of physical structures were used to identify physical limitations of the water distribution subsystem. The main system engineering investigators also relied on the sociology investigators to provide information on socio-organizational constraints to water control.

2. On-Farm Engineering

The on-farm engineering investigators were responsible for evaluating the performance of the water application subsystem. The water application subsystem was defined as the field channel command area. This subsystem shares the same objectives and performance parameters as those of the water delivery subsystem. Because of this, water deliveries into the field channels and field turnouts were evaluated using the same variables as those used by the main system engineers.

The physical data used to evaluate the three performance parameters of adequacy, equity, and reliability included daily flow measurements at the field channel turnout and at selected farm turnouts, acreages of individual allotments and field channel command areas, climatic data used to estimate evapotranspiration, and measurements of deep percolation losses. In addition, longitudinal and cross-sectional profile surveys of selected field channels and observational data on the condition and function of physical structures were used to identify physical limitations of the field channels. The on-farm engineering investigators also relied on the sociology investigators to provide information on organizational and management constraints to water control at the field level.

3. Agronomy

The agronomy investigators were responsible for evaluating the irrigated cropping systems on each scheme. The irrigated cropping system was defined as all of the irrigated acreage cultivated within each irrigation scheme. The primary objective of this system is to attain optimal, sustainable production of irrigated agricultural crops. The performance parameters used to evaluate the irrigated cropping system included cropping intensity, suitability of cropping patterns, and paddy yields. The data used in these comparisons included field channel command acreages, estimates of the acreages of each crop cultivated in each study area, estimates of area occupied by different soil types in each study area, and crop cuttings at the end of the cropping season.

In addition, the agronomy component evaluated several managerial variables thought to affect paddy production, including size of the cultivation unit, time required for land preparation, the quality of land preparation, variety of paddy sown, method of plant establishment, periods of soil moisture stress, timing and type of fertilizers applied, and the effectiveness of weed and insect control measures.

4. Economics

The economics investigators were responsible for evaluating the economic performance of the four irrigation schemes. The economic system was defined as the farm family enterprise and all of the institutional facilities which provide this enterprise with inputs (credit, water, seed, agro-chemicals) and services (extension, storage, transport, and marketing) necessary for profitable production of irrigated agricultural crops. The economic performance of each system was evaluated from estimates of total seasonal farm family income, income derived from the production of irrigated crops, and income from other sources such as property and/or equipment rentals, and on-farm and off-farm employment. Estimates of farm family income were derived from family budgets developed from data collected through structured interviews of farm families. In addition, these interviews provided information on the technical and institutional constraints affecting the performance of the irrigation schemes.

5. Sociology

The sociology component of the diagnostic analysis was responsible for evaluating the social-organizational system. The social-organizational system was defined as the formal and informal organizations responsible for water distribution in each of the four irrigation schemes. Structured interviews of farm families were used to evaluate formal and informal patterns of behavior and organizational arrangements of water distribution. In addition, these interviews provided information on the water users' perceptions of irrigation system operation and of current and future farmer involvement in operating and maintaining the system.

6. Women in Development

A component relating specifically to women was included in the diagnostic analysis to document women's participation in irrigated agricultural production and to provide information on the productivity of highland allotments. Specific information obtained through structured interviews of farm family women included sex-disaggregated data relating to agricultural activities, household activities, and agricultural and household decision-making. In addition, the interviews provided information on income, expenditure patterns, and preferences of the household, including the role of women in family resource management. The interviews also provided information on sources of and access to agricultural information, women's perception of agricultural and field irrigation problems, women's participation in formal and informal organizations, and women's perceptions of the settlement experience.

B. SAMPLING PROCEDURES

Sampling procedures used in the diagnostic analysis were based on expected hydrological differences within and between distributary channels throughout the irrigation scheme. In the 1985 yala investigations, head and tail field channels on three distributary channels located in the head (Block F), middle (RB7), and tail (LB1 of RB21) regions of the D1 main canal of Parakarama Samudara Scheme were selected as common study areas for all disciplines in the diagnostic analysis (Figure 2). In addition to the common study areas, main system engineers measured flow rates on approximately 27 other major offtakes along the D1 main and D1 north canals. Sociology, economics, and women in development investigators also interviewed farm families in the RB1, LB2, and D2 (Weera Padesa) areas of the irrigation scheme in addition to the common study areas.

Common study areas in Giritale consisted of head and tail field channels on two distributary channels located in the head (D4) and tail (D23) regions of the right bank main canal (Figure 3). In addition to the common study areas, sociology, economics, and women in development investigators interviewed farm families located on the D1, D10, D13, and D19 channels of the right bank main canal. Staffing problems in the main system engineering component prevented their participation in the Giritale investigations.

In the 1986 yala investigations, sampling procedures were improved by the addition of more field personnel and increased logistical support. In Minneriya, study areas were expanded to include four major distributary channels located in the head (D4), middle (D21 and D28), and tail (D37) of the Yoda Ela main canal (Figure 4). Two of the distributary channels were of sufficient length (D21 and D28) that it was necessary to divide them into head and tail regions. Hydrologically, the tail regions of these two channels were considered to be representative of tail regions of the scheme. Within each of the six study areas (D4, D21 head, D28 head, D21 tail, D28 tail, and D37), from 4 to 5 field channels along the length of the distributary channels were selected as common study sites for the diagnostic analysis. With the exception of main system engineering, which was responsible for measuring water deliveries at

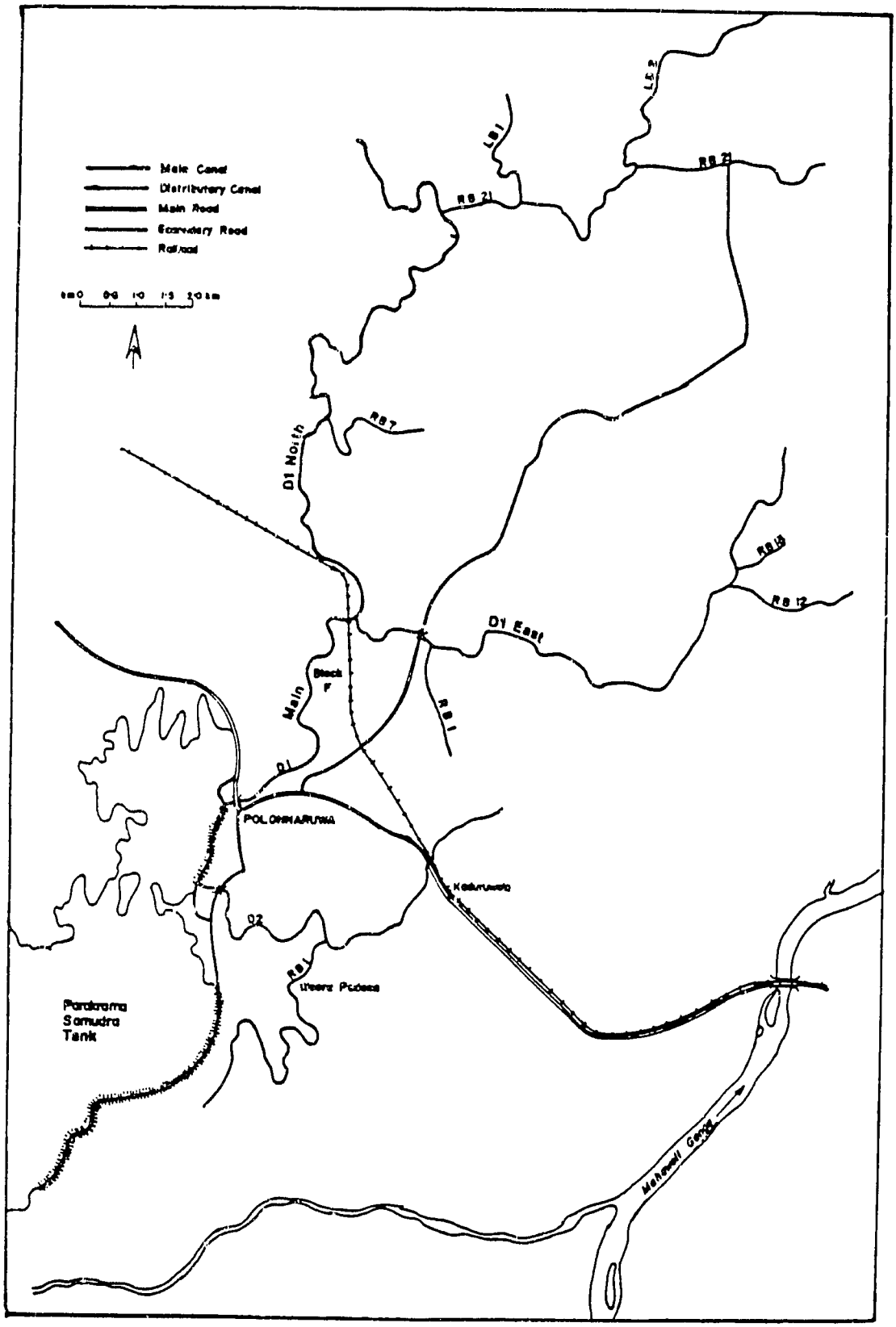

Figure 2. Study sites on Parakrama Samudra Scheme, Polonnaruwa District, Sri Lanka.

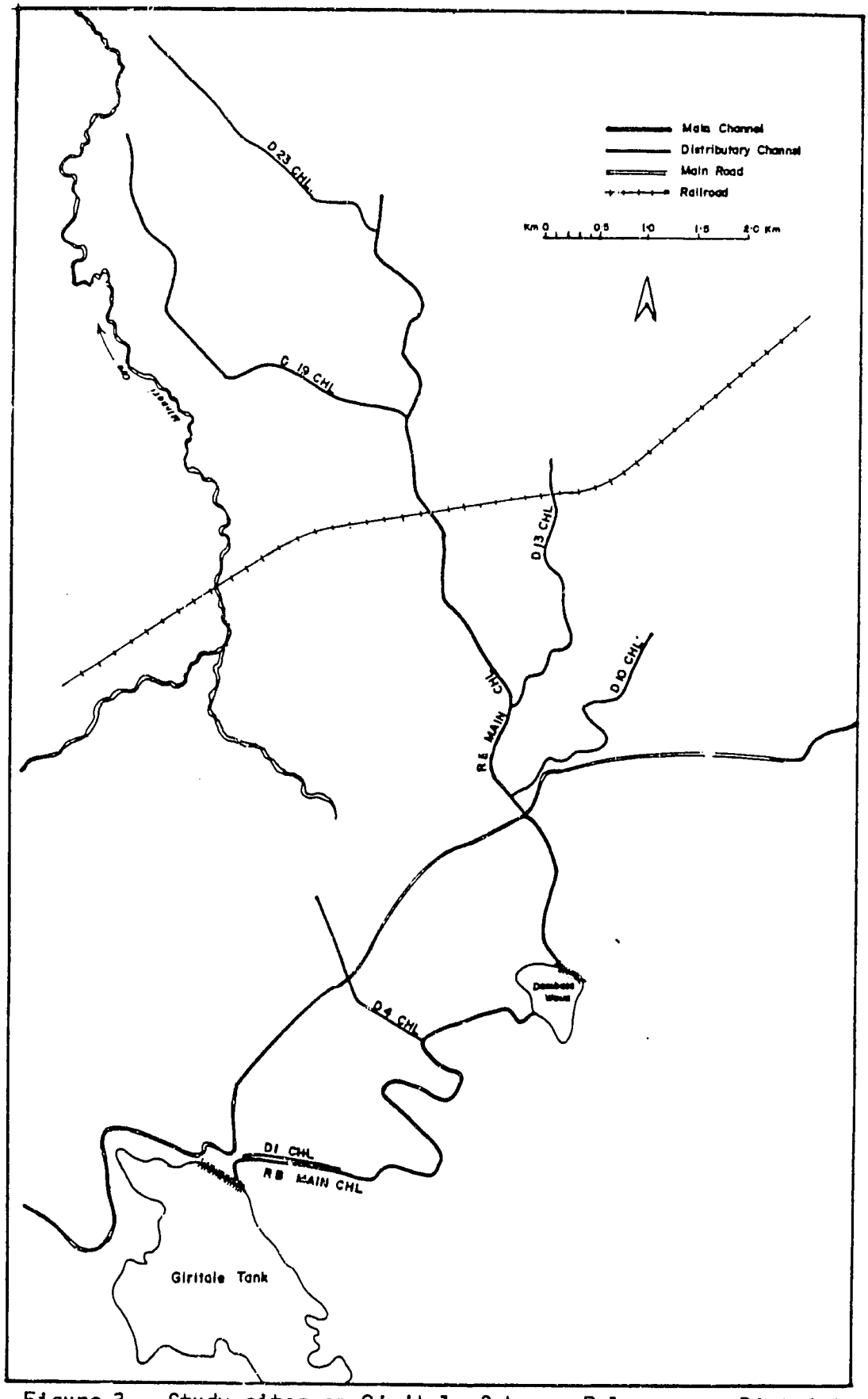

Figure 3. Study sites on Giritale Scheme, Polonnaruwa District, Sri Lanka.

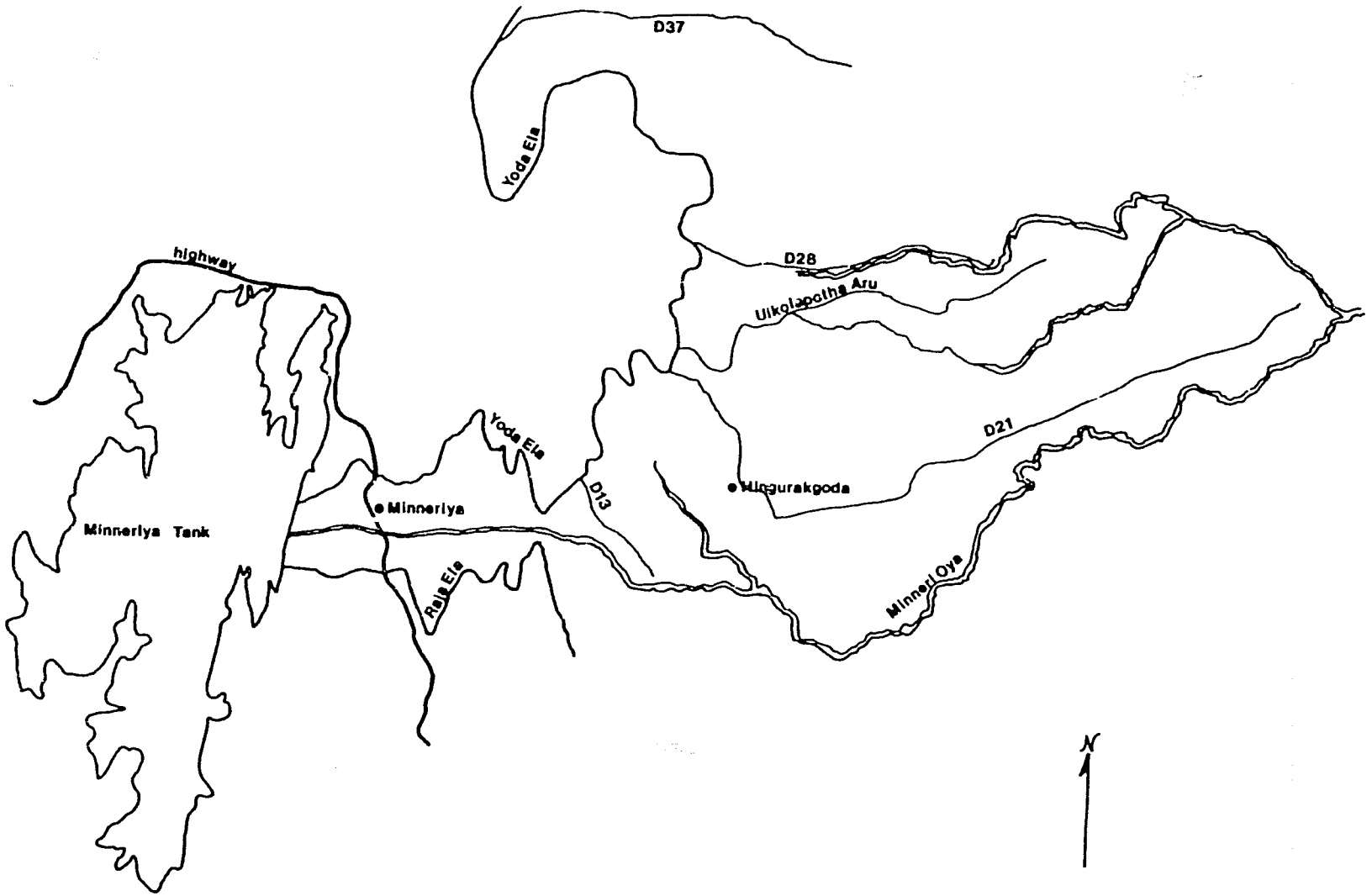

Figure 4. Study sites on Minneriya Scheme, Polonnaruwa District, Sri Lanka.

approximately 63 major supply points along the Yoda Ela, data gathering activities focused on these field channel study sites.

In Kaudulla, six distributary channel study areas were selected from Stage I (Tract 1, D1; Tract 4, D8; and Tract 8, D1) and Stage II (Tract 1, LB Main; Tracts 4 and 5, D1; and Tract 12, D2A) (Figure 5). Along each distributary channel, from 4 to 5 field channels were selected as common study sites for the diagnostic analysis. With the exception of main system engineering, which was responsible for measuring water deliveries at approximately 27 major supply points in Stage I and 31 major supply points in Stage II, data gathering activities focused on these field channel study sites.

C. WMS II SUPPORTING STUDIES

Two WMS II-funded research projects were attached to the Diagnostic Analysis Project to 1) provide specific information on the irrigated command acreages of each scheme, and 2) to provide more detailed information on the social/organizational arrangements of water distribution. The first research project was responsible for producing command area maps of the four irrigation schemes. Command area maps were produced using standard aerial photographic interpretation. Acreage figures obtained from these maps were used by the main system engineering investigators to calculate water deliveries. In addition, the command area map of Parakrama Samudra Scheme served as the base map for later assessments of microcomputer-based image processing and geographic information systems applications of similar Landsat MSS digital data (Martin, 1988).

The second research project was responsible for providing a more detailed assessment of the social-organizational arrangements of water distribution. Research activities of this project focused on Parakrama Samudra and Giritale schemes during 1986 yala.[2]

---

[2]Wilkens-Wells, J., P. Wilkens-Wells, and D.M. Freeman. 1988. Linking main and farm irrigation systems in order to control water, Volume 5: two tank systems in Polonnaruwa District, Sri Lanka. WMS Report 69. Water Management Synthesis II Project, Colorado State University, Fort Collins.

Wilkens-Wells, J. 1988. Management capacity in centrally administered irrigation schemes in Sri Lanka. Colorado State University, Fort Collins. [Dissertation]

Wilkens-Wells, P. [Dissertation in progress]. Department of Sociology, Colorado State University, Fort Collins.

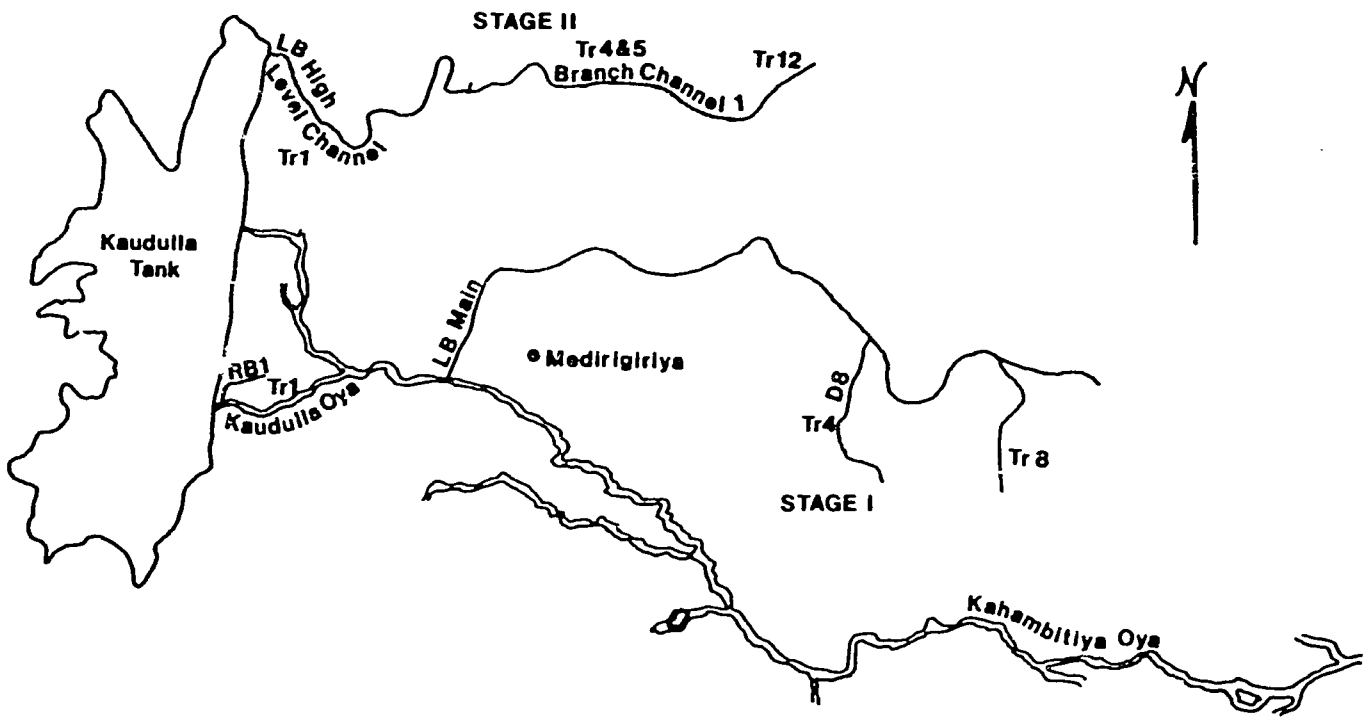

Figure 5. Study sites on Kaudulla Tank, Polonnaruwa District, Sri Lanka.

III. INTERDISCIPLINARY FINDINGS

The interdisciplinary findings of the diagnostic analysis of Parakarama Samudra, Giritale, Minneriya, and Kaudulla irrigation schemes are summarized in the subsequent sections on water control, productivity of agriculture, resource conservation, and farmer involvement.

A. WATER CONTROL

This section of the report is divided into three major subsections. The first subsection summarizes the measurements and observations made concerning water control on the four irrigation schemes. Then, the major factors affecting water control on the four irrigation schemes are summarized. Finally, the effects of inadequate water control on the four irrigation schemes are presented.

1. Measurements and Observations Concerning Water Control

The four irrigation systems investigated were designed to provide a specified command area with full-season irrigation for yala paddy cultivation and supplemental irrigation for maha paddy cultivation. Each system consists of a shallow reservoir (tank) and a gravity-flow delivery system composed of single bank main canals, branch channels, and/or distributary channels which supply water to field channels. Parakrama Samudra Scheme (PSS), the largest and oldest of the four schemes, releases water through three headworks: D1, D2, and D3 sluices. Minneriya tank releases water through two sluices: Raja Ela and Yoda Ela. Kaudulla tank also releases water through two sluices, which are designated as the high-level and low-level sluices because of a 5-ft elevation difference in the sill of the sluices. Giritale, the smallest irrigation system, also has two sluice gates: the right-bank sluice and the left-bank sluice. In addition, Giritale has two small tanks on the right-bank main canal that serve as regulating reservoirs. Of the four tanks, only Kaudulla has the necessary storage to ensure adequate water delivery throughout an entire irrigation season. The storage capacities of the other three tanks are limited. Thus, once irrigation issues begin, nearly continuous tank recharge is necessary by diverting water at Bowatenna from the Mahaweli River.

Another feature of the four irrigation schemes is their operational interdependence. Although each scheme is administered separately, they share the same operational schedule. This provides the Irrigation Department with some flexibility in managing water that is supplied to the tanks. In addition, topographical and geological features often result in each scheme sharing surface and subsurface flows within common boundary areas. By operating each system on a similar schedule, the Irrigation Department can maximize the use of surface and subsurface flows within common boundary areas.

Water measurement data were used to evaluate the physical performance of Parakrama Samudra during 1985 yala, and Minneriya and Kaudulla during 1986 yala. Three performance parameters -- adequacy, equity, and reliability -- were used to evaluate water control on the three irrigation schemes. Personnel problems prevented the collection of similar data on Giritale. However, observations made by other disciplines, supplemented with a few water measurements made during the 1985/86 maha, suggested that the physical performance of Giritale was similar to that of the other three systems. A discussion of the three performance parameters and the various physical and management factors affecting water control follows.

a. Adequacy of Water Delivery

Adequacy was defined as the ability of the system to supply water to adequately meet crop requirements. The adequacy of water deliveries was determined by comparing designed flow rates and/or field irrigation requirements (FIR) with measured water deliveries. The comparisons were made at the sluice gate, distributary channel, field channel, and allotment levels.

Adequacy of the Main System. The overall, weekly average water supply measured at the D1 sluice of Parakrama Samudra (1985 yala), and at both sluice gates of Minneriya and Kaudulla (1986 yala), was 10.3, 10.7, and 12.5 mm/day, respectively. Based on the Irrigation Department design of 37.5 ac/cfs (16.4 mm/day), the overall, weekly average water supply was inadequate on all three systems.

Similar comparisons at distributary channels indicated that 78, 44, and 79 percent, respectively, of the measured distributary channels of PSS, Minneriya, and Kaudulla supplied less than the designed supply set by the Irrigation Department. Calculated weekly average water supply for distributary channels were based on the Irrigation Department's estimates of distributary channel command acreages, which may have underestimated or overestimated actual command areas.

Adequacy at the Field Channel Level. At the field channel level, adequacy of water supply was evaluated based on field irrigation requirements (FIR = ET + seepage and deep percolation). Seasonal average values of FIR for Parakrama Samudra, Minneriya, and Kaudulla were 12.5, 9.2, and 10.3 mm/day, respectively. The calculated FIR values used were conservative estimates of seepage and deep percolation losses and, thus, may have underestimated the actual field irrigation requirement. Even then, comparisons between calculated FIR values and weekly average water supply measured at the field channel headgate indicated that the overall, average weekly water supplied was inadequate in 25 percent to 35 percent of the field channels studied in PSS, Minneriya, and Kaudulla.

Similar comparisons at the allotment level indicated that 43, 37, and 33 percent of the allotments studied on PSS, Minneriya, and Kaudulla were supplied with inadequate water. To compensate for inadequate water deliveries, cultivators with allotments located along drainage channels often supplemented irrigation deliveries with water from the drainage channels. Approximately 33, 27, 16, and 16 percent, respectively, of

the respondents in PSS, Giritale, Minneriya, and Kaudulla reported that they also obtained water for crop production from drainage channels.

Observations and Interviews Regarding Adequacy of Water Delivery. Interviews conducted with farm families in each of the four schemes supported the engineering measurements of water deliveries. Fifty-three percent of the respondents on both PSS and Giritale reported that water deliveries were inadequate during 1985 yala. Similarly, 37 and 88 percent of the respondents, respectively, in Minneriya and Kaudulla reported that water deliveries were inadequate during 1986 yala.

Attempts were made to evaluate the adequacy of water deliveries during three periods of peak water use, using water measurement data and/or ancillary data collected by the other investigative components of the diagnostic analysis. The first period of peak water use occurred during land preparation and was considered by the Irrigation Department to be the most difficult period for water issues.

The irrigation schedule established for 1985 yala and 1986 yala provided for 30 days of continuous water issues for land preparation. However, only 50, 30, and 28 percent, respectively, of the cultivators in study areas of PSS, Minneriya, and Kaudulla completed land preparation within the scheduled period. Therefore, an additional 2 to 2-1/2 weeks were required before more than 95 percent of the cultivators in these areas had completed land preparation.

Delays in land preparation primarily occurred because cultivators took an average of 10 to 17 days to initiate land preparation on the four irrigation schemes. Informal conversations with a few cultivators suggested that delays in initiating land preparation were caused by inadequate water deliveries. Unfortunately, lack of personnel prevented the taking of water measurements on the irrigation schemes until after planting was completed or nearly completed and it was not possible to confirm reports of inadequate water deliveries during land preparation.

The second and third periods of peak water use were identified as the panicle initiation and grain-filling stages of rice growth. However, these periods of peak water use were masked by staggered planting dates, differences in planting methods (transplant versus broadcast), and varietal differences (long-season versus short-season). As a result, it was not possible to determine specific periods of inadequate water deliveries during the cropping season.

Adequacy of Domestic Water. In addition to providing water for irrigated crop production, the four irrigation schemes also served as a source of water for domestic use. Settlers obtain water for drinking and cooking primarily from highland wells. These wells depend on the irrigation system for recharge. The tank and the network of canals are also directly accessed for bathing and laundering. When water issues are reduced or curtailed, the highland wells become inadequate sources of domestic water. This was a particularly acute problem during the off-season, in spite of the Irrigation Department's efforts to provide limited water issues for domestic use. Interviews of farm women on Parakrama Samudra, Giritale, Minneriya, and Kaudulla indicated that 30,

52, 60, and 80 percent, respectively, of the highland wells suffered from low water levels and poor water quality during periods of extended canal closure.

b. Equity of Water Delivery

Equity was defined as the ability of the system to distribute available water supplies among all users on the system. The term available implies water available to the system without regard to the adequacy of the supply. Equity also recognizes that variations in soil type, crops, and planting dates create differences in the amount of water required by each user. Thus, while the yala cropping pattern on the four schemes was essentially a paddy monoculture, variations in soil types and planting dates created differences in irrigation requirements among water users. Equity was evaluated by comparing the average irrigation requirements of distributary and field channel command areas with the average water supplied.

Equity in the Main System. There was a high degree of variability in water supplied to distributary channels in each irrigation scheme. Seasonal average measured water supply to 18 distributary channels along the D1 main and D1 north main canals of PSS during 1985 yala ranged from 6.4 mm/day to 19.4 mm/day. Only six of the distributary channels averaged water supplies near or above the designed supply rate (16.4 mm/day or 0.028 cfs/ac). While distributary channels located in the middle and tail regions of the D1 channel tended to receive less than the designed water supply, overall water supplies to distributary channels throughout the system were highly variable.

Distributary channels in Minneriya and Kaudulla exhibited a wider range of water supply than those investigated on PSS. Seasonal average measured water supply to 45 distribution points along the Raja Ela main canal of Minneriya ranged from 3.3 mm/day to 129 mm/day. Similar figures for distributary channels in Kaudulla ranged from 1.8 mm/day to 34.9 mm/day in Stage I (19 distributary channels), and 1.1 mm/day to 37.9 mm/day in Stage II (36 distributary channels). Variations in water supply to distributary channels occurred throughout Kaudulla with no apparent spatial pattern.

Equity at the Field Channel Level. Average seasonal water supply to field channels was also highly variable on all four schemes. Average measured water supply to six field channels (distributed throughout the head, middle, and tail regions) in PSS for 1985 yala ranged from 7.9 mm/day to 26.5 mm/day. The data also suggested that tail field channels generally received less water than head field channels along the same distributary channel. However, because only field channels at the head and tail of distributary channels were selected for measurement, the actual variability along the entire distributary channel was not evaluated. Similar measurements conducted on head and tail field channels of two distributary channels in Giritale indicated that tail field channels received more water than head field channels.

Improved staffing and logistical support permitted an increase in the number of field channels selected for water measurements in Kaudulla

and Minneriya during 1986 yala. Therefore, from 4 to 8 field channels were selected along the length of each distributary channel study area. These additional field channels were added to determine variability of water supply along distributary channels.

Measured weekly average water supply to 17 field channels located on four distributary channels in Minneriya ranged from 4.3 mm/day to 20.0 mm/day. Similar measured weekly average water supplied to 27 field channels located on six distributary channels in Kaudulla ranged from 4.4 mm/day to 40.6 mm/day. Substantial variations in measured average water supplied to field channels occurred throughout both irrigation schemes, regardless of location along or between distributary channels.

Considerable variation in water supply to allotments was also found on all four schemes. During 1985 yala, measured seasonal average water supplied to 12 allotments ranged from 8.3 mm/day to 25.1 mm/day on PSS. Water measurements conducted during 1986 yala indicated that weekly average water supplied to 31 allotments on Minneriya ranged from 4.3 mm/day to 28.8 mm/day. Similar figures for 31 allotments on Kaudulla ranged from .2 mm/day to 44.7 mm/day. Although inequitable water supplies occurred throughout the command areas of all four schemes, there was an observed tendency for allotments located at the head of field channels to receive more water than those located at the tail of the same field channel.

Equity of Domestic Well Water. Interviews of farm women indicated that the hydrological position of the highland affected the adequacy of domestic well supply. During 1985 yala, 21 percent of the households in the head regions of PSS reported domestic well water problems, compared to 16 percent from the middle and 46 percent from the tail regions. The figures for the head, middle, and tail regions of Giritale were 41, 60, and 61 percent, respectively. During 1986 yala, 37 percent of the households in the head regions of Minneriya reported domestic well water problems, compared to 64 percent from the middle and 72 percent from the tail regions. The figures for the head, middle, and tail regions of Kaudulla were 70, 84, and 83 percent, respectively.

c. Reliability of Water Delivery

Reliability was defined as the ability of the system to deliver the required amount of water on a pre-determined schedule known by the water user. Implied in this definition is that the flow rate, duration, and frequency of water deliveries match the water requirements of the individual users. Reliability of water supplies was evaluated by comparing planned water deliveries with measured water deliveries throughout the main system and on field channels in each irrigation scheme. To accomplish this, inflow hydrographs were constructed for all supply points in which daily water measurements were collected.

Planned Yala Irrigation Schedules. The Irrigation Department developed yala irrigation schedules for each of the irrigation schemes at the end of the maha irrigation season. The irrigation schedule developed for each scheme specified a period of approximately one month of continuous flow for land preparation and a period of approximately 95 days

of rotational water issues for crop production. The schedules also provided detailed information on the rotational schedules for the main canals, distributary channels, and field channels in each scheme.

Three to four weeks prior to the start of the yala irrigation season, a kanna (cultivation) meeting was held for each irrigation scheme. The primary purpose of the kanna meeting was to present the final irrigation schedule to the cultivators of each scheme. Among other things, the schedule specified the dates for the start and completion of continuous water issues for land preparation and the start and completion of rotational water issues for crop growth. Information regarding the specific rotational schedules of main canals, distributary channels, and field channels was not presented. Although the kanna meeting was the only formal method used to inform cultivators about the planned irrigation schedules, few cultivators attended the kanna meetings. Apparently, most cultivators relied on the vel vidanes, patrol laborers, and the few cultivators who attended the meeting to inform them about the schedule. It is also possible that many cultivators waited to begin cultivation activities until they observed water flowing in the canals, since irrigation schedules were similar from year to year.

Actual Yala Irrigation Schedules. In none of the four irrigation schemes was the yala irrigation schedule implemented as it was presented to the cultivators in the kanna meeting. Although water deliveries were initiated on or before the scheduled dates, continuous water issues had to be extended by 2 to 3 weeks on all four schemes because only 28 to 50 percent of the cultivators had completed land preparation within the scheduled period. The 2-to-3-week extension in continuous water issues also meant that later water issues had to be extended by an additional 2 to 3 weeks on all four irrigation schemes.

Reliability of Water Deliveries. Although the operational schedule indicated that water issues would be continuous during the one-month land preparation period, rotational water deliveries during land preparation were observed on portions of the command areas of all four schemes. According to the Irrigation Department, rotation of water deliveries was necessary because cultivators complained that flow rates were inadequate for proper land preparation.

Although rotational water issues were later implemented on all four schemes, rotational schedules for main canals and distributary channels were not implemented according to the planned rotations. For example, the planned rotational schedule for the D1 main canal of PSS was 12 days of water delivery followed by 2 days of closure. In practice, delivery periods ranged from 12 to 27 days, and closures from 2-5 days. Similarly, rotational periods specified for the Block F, RB7, and LB1 of RB21 distributary channels of PSS were 3.5 or 4 (LB1 of RB21) days of water deliveries followed by 2.5 or 2 (LB1 of RB21) days of closure. In practice, delivery periods on these three distributary channels ranged from 2 to 5 days, and closure periods ranged from 1 to 5 days. Finally, field channel rotations of water deliveries were specified by the Irrigation Department for many of the PSS distributary channels. However, rotation of water issues among field channels was not observed on PSS.

According to the Irrigation Department, deviations from the planned rotation occurred as a result of variations in demand within the irrigated command area. Changes in rotation were often made at the request of the cultivators. However, unplanned changes in rotational water issues were not announced. Because of this, 33 percent of the cultivators interviewed on PSS and 46 percent of the cultivators interviewed on Giritale reported that the Irrigation Department did not follow the yala irrigation schedule.

Another aspect of reliability deals with the ability of the system to provide supply points along the system with a consistent, specified flow rate during irrigation deliveries. Daily flow measurements at the sluice gates and at selected distributary channel and field channel offtakes in all four irrigation schemes showed substantial fluctuations in flow rates within the between issue periods. During 1985 yala, daily flow rates in the LB1/RB21 distributary channel of PSS fluctuated from 17 percent to 190 percent of the average measured flow rate. Similar fluctuations in flow rates were observed in distributary channels on Kaudulla and Minneriya. In all four irrigation schemes, inflow hydrographs of field channels and farm turnouts typically showed large variations in flow rates within and between issue periods. Typically, peak flows only occurred during a single day of the 3-5 day water issue period.

Reliability of Highland Wells. As mentioned earlier, highland wells depended on the irrigation system for recharge. When water issues were reduced or curtailed, the highland wells became unreliable sources of domestic water. Interviews with farm family women on Parakrama Samudra, Giritale, Minneriya, and Kaudulla indicated that 30, 52, 60, and 80 percent of the highland wells, respectively, suffered from low water levels and poor water quality during periods when water issues were reduced or curtailed.

2. Factors Affecting Water Control

In the previous section of this report, it was shown that PSS, Minneriya, and Kaudulla irrigation schemes lacked the water control needed to provide adequate, equitable, and reliable water deliveries. In this section of the report, physical and management factors affecting water control on the four irrigation schemes are summarized.

a. Command Area

Since restoration, uncontrolled conversion of lands to agricultural production within and outside of the originally designed irrigated command areas has resulted in significant increases in the irrigated command areas of each scheme. Measured acreages in PSS, Giritale, and Minneriya (Martin, 1988) indicated that the irrigated command areas of these three systems have increased by 24, 14, and 25 percent, respectively, from the original designed command area. Although similar figures for Kaudulla were incomplete, acreage figures obtained for portions of Stage I and all of Stage II suggested that the irrigated command area of Kaudulla had increased by an amount similar to that observed on PSS.

Over time, the majority of these lands were given legal access to water through the construction of additional channels. However, the main delivery systems, which were designed to provide continuous flow with rotations at the field channel level, remained essentially unchanged. Instead, the Irrigation Department initiated rotational water issues at the main system level (main channel and/or distributary channels). According to the Irrigation Department, the rotational water issues were adopted to supply water above the designed full supply level. While this management practice assured that water was spread over the additional command areas, it did not solve the problem of providing adequate water supplies. Rather, it created an additional set of management problems, amplified inherent physical deficiencies in the conveyance systems, and accelerated the physical deterioration of conveyance systems; all of which were further aggravated by inadequate funding for operations and maintenance.

b. Carrying Capacities of Main Canals

The carrying capacities of main canals on all four irrigation schemes are inadequate to supply water to the present command areas. The D1 main canal of PSS provided a typical example of the inadequate carrying capacities of the main canals. The D1 main canal was designed to provide a maximum flow rate of 350 cfs to a designed command area of 15,433 ac. Measurements of PSS command area by Martin in 1986 indicated that the D1 command area had increased by 25 percent to approximately 19,346 ac. During 1986 yala, the average measured discharge for the D1 sluice was 340 cfs during the flow periods of rotations. This indicated that the canal was operating above the designed level most of the time with less than 2 to 3 inches of freeboard. In fact, the maximum observed flow rate was 456 cfs. Comparisons of supply with conservative estimates of field irrigation requirements indicated that requirements were generally higher than the supply, especially during the late vegetative and early flowering periods of plant growth. Similar comparisons on Kaudulla and Minneriya indicated that water requirements were also generally higher than the water supplied.

On PSS, adequacy of water deliveries to the tail of PSS were also substantially affected by an aqueduct located on the D1 north main canal below the RB7 distributary channel. The carrying capacity of this aqueduct was insufficient for the estimated command areas located below the aqueduct.

c. Water Control and Measuring Structures

Control structures needed to ensure equitable water distribution were either absent or were inadequate on all four irrigation schemes. In addition, PSS, Giritale, and Minneriya lacked water measuring structures to monitor water delivery. While staff gauges were installed throughout the conveyance system of Kaudulla by a previous research project, the use of staff gauges to monitor flow rates was not integrated into operational plans of the Irrigation Department.

d. Cropping Patterns and Soil Types

The cultivation of paddy on reddish-brown earth soils was regarded as a major factor contributing to inadequate and inequitable water distribution on all four irrigation schemes. Reddish-brown earth soils are poorly suited for paddy cultivation because of their high deep percolation losses. Average deep percolation losses for reddish-brown earth soils planted with paddy were 9 mm/day compared to 2 mm/day for low humic gley soils. Soil surveys conducted within the study areas suggested that more than 60 percent of the command areas of the four irrigation schemes were occupied by reddish-brown earth soils. However, only 4 to 6 percent of these soils were planted with crops other than paddy.

e. Regulations

Although clearly defined regulations relating to the violation of the Irrigation Ordinance exist, their proper and swift implementation and enforcement is hampered by delays in court procedures against offenders. As a result, many cultivators take water out of turn, cultivate lands set aside as government easement property, and use irrigation water for highland cultivation. Cultivators on Parakrama Samudra, Giritale, Minneriya, and Kaudulla reported that 29, 20, 30, and 28 percent of cultivators, respectively, take water out of turn.

Nearly all of the lands set aside as government easement property bordering field channels, drainage channels, and field channel access roads were under permanent cultivation on all four irrigation schemes. Field channel surveys indicated that encroachment onto government easement property had increased field channel command areas by an average of 12 percent. The additional demands created by encroachment contributed to inadequate and inequitable water deliveries.

In addition, many of the highland homesteads accessed irrigation water from nearby canals or irrigation channels. Nearly 30 percent of the households interviewed on PSS and 20 percent of the households interviewed on Giritale indicated that they were growing irrigated crops on the highlands. Interviews of households in Minneriya suggested that over 30 percent of the highlands accessed irrigation water, whereas less than 10 percent of the Kaudulla households reported illegal access of irrigation water.

f. Maintenance of Conveyance Systems

Inadequate funding for maintenance and inadequate participation of cultivators in maintenance activities has resulted in significant deterioration of the conveyance systems of PSS, Giritale, and Minneriya. Cross-sectional areas of channels have changed due to erosion and sedimentation. In addition, structural deterioration and damage have severely affected the function of existing structures on these three irrigation schemes. The degree of deterioration of the channels and hydraulic structures was observed to increase from the sluice gate to the field outlets. While similar problems were observed on Kaudulla, the degree of deterioration was significantly less.

g. Irrigation Department Administration

Currently, the acreage figures used by the Irrigation Department to calculate required water deliveries are based on visual estimates of subcommand acreages by field officers and, thus, are subject to errors. As a result, calculated water deliveries often overestimated or underestimated the actual water demand. In addition, the use of a standard water duty (30-40 ac/cfs) does not account for variations in soil types or for conveyance losses. The diagnostic analysis also identified soil type as a major factor affecting adequacy of water supply within and between field channels. However, the basic soil survey information needed to plan water deliveries was lacking on all four irrigation schemes.

The ability of the Irrigation Department staff to manage rotational water issues at the distributary level was limited by departmental regulations that placed restrictions on travel and official vehicle use. These problems were amplified by the lack of communication facilities between the field and the irrigation engineers' office. More importantly, the performance of department staff was affected by cumbersome bureaucratic procedures that often delayed O&M decision-making. The lack of adequate office, housing, schooling, and health care facilities in the district also contributed to personnel difficulties.

Provisions for domestic water are only informally included in the management of the irrigation system. Special water issues to recharge highland wells are based on demand, experience, and intuition rather than integrated into the operational plan for the irrigation system.

h. Organizational Structure Below the Distributary Channels

Traditionally, management of water deliveries below the distributary channel was the responsibility of a locally elected vel vidane. The vel vidane was responsible for supervising water rotations along distributary channels and the cleaning of channels. Vel vidanes also served as mediators of water-related disputes. For these services each water user paid the vel vidane 1.5 bu of paddy at the end of each irrigation season.

However, the role of the vel vidane has been undermined by government policy decisions made over the last several decades. First, many of the responsibilities of the vel vidane were transferred to colonization officers and cultivation committees in the Agrarian Services Department by the Paddy Lands Act in 1958. Then, in 1972, the government eliminated the vel vidane with the creation of agriculture productivity committees. In 1979, vel vidanes were reinstated by the Agricultural Services Act. However, this act also transferred responsibility for dealing with water disputes and water distribution from the vel vidane to politically appointed cultivation officers. Consequently, most of the responsibilities of the vel vidane were assumed by the colonization officers and cultivation officers of the Agrarian Services Department.

With the introduction of the Project Committee System in 1984, the role of the vel vidane became more confused. At the time these studies were conducted, the Project Committee System was attempting to organize cultivators for more effective participation in irrigation system management. At the field channel level the Project Committee System created the ela niyojitha, a locally elected cultivator responsible for representing the field channel group at the distributary channel level. Sometimes the ela niyojitha and the vel vidane were the same person. When they were not, confusion about their roles and responsibilities existed.

3. The Effects of Inadequate Water Control

In previous sections on water control, observations and measurements documented problems of water control and factors which contributed to these problems on the four irrigation schemes. In this section, the effects of inadequate water control are presented from both a physical and managerial aspect. While some effects of inadequate water control can be easily classified as either physical or managerial, the majority involved a combination of physical and managerial problems.

a. Conveyance System

As a result of inadequate water control, main canals were operated at flow rates that exceeded their design. Consequently, with 2 to 3 inches of freeboard, the potential of breaching a main canal, canal erosion, and damage to the canal and existing structures is greatly increased. These effects, while physical in nature, also lead to further management problems.

For example, the danger of issuing water in amounts above design specifications for canals results in tension and stress between farmers and the Irrigation Department. The irrigation engineers are under constant strain to regulate and moderate flow rates while attempting to deliver an adequate, equitable, and reliable water supply to the entire irrigation system. As a result, unannounced changes in water issues, erratic flow rates, and undetermined periods of flow are common. In effect, a great deal of time and effort is spent by the irrigation engineer responding to water control problems, rather than implementing the designed operational plan. This kind of system operation also affects the management practices of the cultivator, making it difficult to coordinate labor, draft, equipment, and other agricultural inputs necessary for cultivation.

b. Paddy Yields

Another primarily physical effect of inadequate water control may be seen in the reduced paddy yields observed on all four irrigation schemes. Potential yala paddy yields on the four irrigation systems were estimated to be around 120-130 bu/ac. However, during 1985 yala, average paddy yields for Parakrama Samudra and Giritale were approximately 90 bu/ac and 88 bu/ac. Similarly, average paddy yields during 1986 yala on Minneriya and Kaudulla were approximately 93 bu/ac and 67 bu/ac.

Significant variations in average paddy yields existed between allotments, field channels, and distributary channel study areas on all four irrigation schemes. These variations corresponded to the measured variability of water supply within field channels and between field channels and distributary channels on each scheme. While both water supply and yields were highly variable throughout all levels of the four irrigation schemes, generally, no correlation was observed between location and supply or location and yields. The only notable exception occurred at the tail study site of PSS. Both water supply deliveries and average paddy yields were significantly lower than those in the head and middle study sites of PSS. Deficiencies in water deliveries and the resulting low paddy yields in the tail areas were attributed to the limited carrying capacity of the aqueduct located on the main channel below the RB7 distributary channel.

c. Crop Management Decisions

Crop management decisions made by cultivators on all four irrigation schemes were affected by inadequate water deliveries and the associated risk of crop failure. Some of the management decisions affected by inadequate water deliveries are presented below.

Crop Selection. Undependable yala irrigation deliveries were cited by cultivators as one of many reasons for preferring paddy cultivation during yala. The lower investment costs of paddy production compared to those of other field crops decreased the economic impact of possible crop failures on the farm family. However, this preference for paddy cultivation limited potential crop diversification and the potential for the farm families to receive higher economic benefits.

Varietal Selection. Despite the recommendation at the kanna meeting to grow short-season paddy varieties during the yala cultivation season, 43, 18, 34, and 16 percent of the cultivators in Parakarama Samudra, Giritale, Minneriya, and Kaudulla, respectively, reported that they planted long-season paddy varieties. Informal interviews of cultivators in the study areas indicated that long-season paddy varieties were preferred because of their higher potential yields and their longer vegetative period. It was reasoned by cultivators that the longer vegetative period improved the plants' ability to recover from temporary periods of inadequate soil moisture. However, the cultivation of long-season paddy varieties, particularly broadcast long-season paddy varieties, contributed to extensions of the yala irrigation season.

Planting Method. Many cultivators indicated that they broadcast paddy in order to lower production costs because unreliable water deliveries during yala increased the risk of crop failure. Approximately 54, 70, 76, and 62 percent of the study areas of PSS, Giritale, Minneriya, and Kaudulla, respectively, broadcast yala paddy. While broadcast sowing does reduce production costs, fields are broadcast 25 to 35 days earlier than transplanted fields. Thus, exposure of broadcast fields to possible periods of water shortage is greater and the water requirements of the crop are higher.

Weed Control. Weed infestations were very high on all four irrigation schemes. Field observations indicated that weed infestations were a primary factor in reducing paddy yields. Many cultivators indicated that initial weed infestations were severe because of inadequate water during the land preparation period. Furthermore, many cultivators failed to control weeds with herbicides because they were unable to maintain standing water in the field after the herbicide application. As a result, the fields were reinfested with new weed growth.

d. Unauthorized Irrigation

When water deliveries are inadequate, many cultivators supplement irrigation water with water from drainage channels or take water out of turn. Interviews conducted on Parakarama Samudra, Giritale, Minneriya, and Kaudulla indicated that 33, 27, 16, and 16 percent, respectively, of the cultivators supplemented irrigation water with water from drainage channels. When cultivators block or obstruct drainage channels, this results in increased physical problems for the irrigation system and causes management difficulties for the Irrigation Department.

As another indication of inadequate water, cultivators on the four irrigation schemes reported that 29, 20, 78, and 72 percent of the other cultivators in their area in PSS, Giritale, Minneriya, and Kaudulla, respectively, took water out of turn. This disregard for irrigation regulations not only leads to disputes among cultivators, but increases the conflict between the Irrigation Department and cultivators.

e. Disputes and Conflicts

Inadequate enforcement of regulations relating to the Irrigation Ordinance has significantly increased disputes and conflicts concerning irrigation water. Interviews of farm families on Parakrama Samudra, Giritale, Minneriya, and Kaudulla indicated that 33, 46, 30, and 17 percent of the cultivators, respectively, were involved in water disputes. The interviews also indicated that there was a considerable degree of confusion among cultivators about the current organizational structure provided to settle disputes. Although some cultivators correctly reported irrigation offenses to officers of the Agrarian Services Department, most cultivators reported offenses to either the vel vidane or Irrigation Department officers (neither of whom have authority to deal with such problems). While cases may be referred to the civil courts, this action was generally regarded as unsatisfactory because of legal expenses, lengthy procedures, and political interference by influential individuals. Most individuals interviewed expressed concern over this problem, and the inability to effectively settle irrigation-related disputes was a major issue discussed at community meetings.

f. Domestic Water Supply

That many highland wells become inadequate sources of domestic water between irrigation seasons was regarded as a major inconvenience to most farm families. In addition to the inconvenience of hauling water for domestic use, the lack of water prevented farmers from es-

tablishing nurseries or home gardens on the highland homesteads when highland wells were low.

B. AGRICULTURAL PRODUCTIVITY

The reputation of Polonnaruwa District as the rice bowl of Sri Lanka is largely derived from the paddy produced by the four major irrigation schemes (Parakrama Samudra, Giritale, Minneriya, and Kaudulla) where these investigations were conducted. Until recently, average paddy yields for Polonnaruwa District have consistently been 10-20 bu/ac higher than those reported for other districts in Sri Lanka.

1. Measurements and Observations Concerning Productivity

Engineering, agronomic, economic, and women in development data collected on the four irrigation schemes were used to evaluate three performance parameters of agricultural productivity: cropping intensity, cropping patterns, and crop yields. Cropping intensities and cropping patterns in the irrigated command area were estimated from engineering and agronomic surveys of the study sites. Crop cuttings conducted at each study site were used to estimate paddy yields for the irrigated command area of each scheme. Staffing limitations prevented this level of data collection on the highland homesteads. Instead, information collected through structured interviews provided an indication of existing cropping intensities and cropping patterns on the highland homesteads. A discussion of the three performance parameters and the various physical and managerial factors affecting them follows.

a. Cropping Pattern

Although soil survey information suggested a potential for cultivating yala crops other than paddy on approximately 35-45 percent of the irrigated command area of each of the four irrigation schemes, the four systems were essentially paddy monocultures. During the 1985 yala cropping season, paddy cultivation accounted for approximately 96 percent of the irrigated command area of Parakrama Samudra and approximately 95 percent of the irrigated command area of Giritale. Similar figures for Minneriya and Kaudulla during 1986 yala were approximately 96 percent and 91 percent, respectively. Other field crops cultivated were chili, tobacco, pulses, and very small areas of vegetables, which were usually grown on threshing floors and paddy field bunds.

In contrast to the irrigated allotment, a wide variety of vegetables and permanent tree crops were grown on the non-irrigated highland allotments. The most common tree crop was coconut, followed by mango, banana, and jackfruit. In addition, a wide variety of other tree crops were also reported. These included papaya, breadfruit, guava, orange, lemon, lime, tamarind, pomegranate, areca nut, cashew, palmyrah, king coconut, wood apple, and custard apple. Some of the most common vegetables grown in the highland gardens were manioc, yams, and sweet potato due to their ease of cultivation and drought tolerance. Other common vegetable crops included cowpea, long beans, and lady's fingers (okra). A scattering of other vegetables such as tomato, loofa, green gram, brinjals (eggplant), snakegourd, onion, spinach, and pumpkin were also reported.

When the highland had access to irrigation water, cash crops such as paddy, chili, or tobacco were usually cultivated.

b. Cropping Intensity

Cropping intensities in the irrigated command areas of PSS and Giritale were between 98 and 99 percent during 1985 yala. Only 300-400 ac of the original 19,600 ac were not under the command of the irrigation system. The majority of this area was located in the tail of the RB21 channel of the D1 north main canal. According to the irrigation engineer, errors in the original design and construction prevented the Irrigation Department from delivering water to this area during yala. Similar irrigated cropping intensities for Kaudulla and Minneriya during 1986 yala were 97 percent and 95 percent, respectively. Fallow areas on these two systems primarily consisted of elevated land within field channels that could not be commanded by the gravity flow irrigation scheme. Comparisons of the original blocking-out plans with field surveys indicated that much of this land had originally been intended for irrigation.

In general, cropping intensities on the highland homesteads were low on all four irrigation schemes. Interviews of farm family women indicated that from 4 percent of the PSS highlands to 25 percent of the Kaudulla highlands consisted of rock outcroppings and shallow soils which prevented crop cultivation. Permanent tree crops were cultivated on 96, 100, 92, and 75 percent of the respective highland homesteads of PSS, Giritale, Minneriya, and Kaudulla. However, gardens were only found on approximately 29, 28, 29, and 38 percent of the respective highland homesteads of PSS, Giritale, Minneriya, and Kaudulla. Most highland gardens were limited due to insufficient rainfall and the absence of irrigation water. Interviews indicated that cash crops were cultivated on approximately 20 percent of the highland homesteads of Giritale and 29 percent of the highland homesteads of PSS during 1985 yala. Most of these larger cropped extents were illegally irrigated from nearby irrigation channels.

c. Crop Yields

According to the Agriculture Department, the new high yielding paddy varieties have potential yields of 140 bu/ac or more when grown under optimum conditions. However, potential yields are seldom achieved in actual field situations. More realistic potential yala paddy yields would probably range from 120 to 130 bu/ac. Crop cutting surveys conducted on PSS and Giritale during 1985 yala and on Minneriya and Kaudulla during 1986 yala only averaged 90, 88, 93, and 67 bu/ac, respectively. While average paddy yields for PSS, Giritale, and Minneriya were above those obtained on most irrigation schemes in Sri Lanka, they were substantially lower than the potential. The fact that paddy yields on Kaudulla were significantly lower than those of the other four systems indicated that irrigated agricultural production problems were greater on this system.

Furthermore, there was considerable variation in paddy yields within and between study sites on all four irrigation schemes. Coefficients

of variation in paddy yields ranged from 40 percent to 260 percent on PSS, 30 percent to 120 percent on Giritale and Minneriya, and 20 percent to 180 percent on Kaudulla.

With the exception of the highland homesteads with access to irrigation water, productivity of the highland homesteads was low. Interviews with farm family women indicated that highland gardens and permanent tree crops were primarily grown for home consumption. Only 26, 18, 23, and 20 percent of the women on PSS, Giritale, Minneriya, and Kaudulla, respectively, reported occasional sales of fruit, vegetables, or coconuts.

2. Factors Affecting Productivity

Several factors affected the agricultural productivity of the irrigated lowlands and non-irrigated highlands on all four irrigation schemes. While some of these factors were obviously physical or managerial, most were a combination of physical and managerial problems affecting agricultural productivity.

a. Water Availability

Physically, agricultural productivity on the lowland allotments of all four irrigation schemes was limited by inadequate water supplies during land preparation, and by periods of inadequate water supplies during the yala cultivation season. Only 50, 30, and 28 percent of the cultivators in study areas of PSS, Minneriya, and Kaudulla completed land preparation within the scheduled period. An additional 2 to 2-1/2 weeks was required before more than 96 percent of the cultivators completed land preparation. Informal conversations with a few cultivators indicated that extended land preparation periods were required because water supply during the land preparation period was inadequate. Observations of weed infestations during the season also indicated that excessive weed growth in many fields resulted from poor land preparation.

During the cultivation season, periods of soil moisture stress ranging from 1 to 6 days were observed during the late vegetative and early flowering stages of rice growth in many of the paddy fields in the study areas of PSS, Minneriya, and Kaudulla. Soil moisture stress during these critical stages of plant growth was a major factor contributing to lower yields. In addition, paddy yields in many fields were also affected by excessive weed growth. Many cultivators indicated that attempts to control weeds with herbicides failed because they were unable to maintain standing water in the fields after the herbicide was applied.

The lack of a source of irrigation water was cited by farm family women as a major reason for the low productivity of the highland homestead in all four irrigation schemes. However, when the highland homestead had access to irrigation water, the preference was to cultivate cash crops such as paddy, chili, or tobacco, rather than vegetables for home consumption.

b. Soil Type

The second major physical factor affecting agricultural productivity in the lowland allotments on all four irrigation schemes was soil type. Nearly 60 percent of the irrigated acreage of these four schemes was composed of reddish-brown earth soils. Reddish-brown earth soils are poorly suited for paddy cultivation because of their high deep percolation losses and low moisture holding capacities.

Reddish-brown earth soils were the predominant soil type in the highland homesteads. Although a large variety of highland crops were grown on these soils, from 4 percent (PSS) to 25 percent (Kaudulla) of the highland soils were too shallow for agricultural use.

c. Agricultural Inputs

Seed. While essentially 100 percent of the study areas in the four irrigation schemes were planted with new high-yielding paddy varieties, field observations suggested that many cultivators used poor quality seed. Structured interviews conducted with cultivators on Minneriya and Kaudulla indicated that more than 95 percent of the cultivators used their own seed or seed acquired from their neighbors. Several cultivators indicated that the certified seed they had obtained from the Certified Seed Division of the Agriculture Department had poor germination. As a result, they had to replant their fields with seed from their own or other cultivators' stocks.

Fertilizer. Observational data collected on fertilizer applications indicated that a majority of cultivators on the four irrigation schemes did not follow the Agriculture Department's fertilizer recommendations for paddy. Although fertilizer applications were higher than expected, most cultivators on the four irrigation schemes applied less than the recommended rate of basal fertilizer and more than the recommended rate of fertilizer for the first and second top dressings. Few cultivators applied a third top dressing. Plant tissue tests in selected fields within each irrigation system indicated that tissue levels of nitrogen and phosphorus were adequate to excessive, while potassium levels were low.

Other Agro-chemicals. Although a wide variety of herbicides and insecticides were used by cultivators on all four systems, few cultivators applied them correctly. Weed counts in paddy fields indicated that only about 30 percent of the cultivators successfully controlled weed infestations with herbicide applications. Observations indicated that insect infestations often encompassed nearly 30 to 45 percent of a field before insecticides were applied. As a result, significant damage usually occurred before insecticides were applied. Furthermore, cultivators often mixed more than one insecticide with soap, urea, sulfur, and other compounds, with little knowledge of the potential hazards to themselves or the crops.

d. Agricultural Extension

Inadequacies in the agricultural extension system probably contributed to misuse or poor utilization of agricultural inputs on the four irrigation schemes. Most cultivators also lacked knowledge concerning the cultivation of subsidiary crops, which limited the potential of crop diversification on all four irrigation schemes. Observations indicated that from 10 to 15 percent of the cultivators were unable to identify, or incorrectly identified, the paddy variety they planted during yala.

Farm families on all four irrigation schemes reported that their primary source of agriculture information was gained through informal means (traditional experience, family members, other cultivators) and from private traders rather than from agricultural extension personnel. In addition, women on the four irrigation schemes reported that they also obtained agricultural information from radio programs and newspaper articles. Few women on the four irrigation schemes reported any personal contact with agricultural extension personnel.

Limited conversations with Agricultural Department personnel suggested that the effectiveness of most KVS officers was limited by many of the same factors that affected the performance of field officers in the Irrigation Department. Many of these officers reported that their performance was affected by cumbersome bureaucratic procedures, limitations on travel and official vehicle use, inadequate office and housing facilities, and the lack of schooling and health care facilities in the district. In addition, contact with farm families was limited as each KVS was responsible for approximately 500 households.

e. Credit

The relative inaccessibility of institutional sources of credit was also regarded as a major factor affecting paddy cultivation and potential diversification on all four irrigation schemes. Approximately 50, 25, 58, and 55 percent of the respective cultivators in PSS, Giritale, Minneriya, and Kaudulla obtained loans for the yala cultivation season. However, only 41, 69, 52, and 24 percent of the above cultivators, respectively, obtained low interest loans (9 to 12 percent) through banks or cooperatives. The remainder obtained loans from other family members or private traders with annual interest rates that ranged from 0 to 240 percent. Many of those who resorted to non-institutional credit were forced to do so by factors such as previous loan default, inability to secure necessary documents, complicated bureaucratic procedures adopted by the lending institutions, and easier access to private credit. Due to the overall limitations of the family budget and cash shortages during the cultivation season, approximately 22, 40, 13, and 52 percent of the PSS, Giritale, Minneriya, and Kaudulla households, respectively, borrowed small amounts of cash from neighbors or boutiques for daily needs. Another common means of acquiring cash for use during the cultivation season included pawning radios, bicycles, and women's jewelry.

f. Storage and Marketing

Governmental policy and programs for storage and marketing of paddy had a positive influence on commercial paddy production on all four irrigation schemes. Although only 3, 2, 7, and 1 percent of the cultivators of PSS, Giritale, Minneriya, and Kaudulla, respectively, marketed their paddy through government marketing agents, the fact that the government offered a guaranteed price for paddy and provided marketing agents and limited facilities for the purchase of paddy assured that the market value of paddy remained relatively stable throughout the year. However, a majority of cultivators marketed paddy to private traders because of better prices, lower standards, and the convenience of farm-gate purchase. In addition, many cultivators sold their paddy to private traders to settle previous debts incurred. The average price received by cultivators for paddy marketing during 1985 yala for PSS, and 1986 yala for Minneriya and Kaudulla was Rs. 77.20, Rs. 77.10, and Rs. 71.60, respectively. The price received by individual cultivators for paddy during the two yala seasons ranged from a low of Rs. 62 to a high of Rs. 92.

While government policy and programs for paddy marketing and storage stimulated commercial production of paddy, the lack of similar programs for other commercial crops severely constrained efforts to diversify cropping patterns on the four irrigation schemes. For example, the lack of storage facilities and of a government-guaranteed price for chili resulted in farm-gate price fluctuations from approximately Rs. 70/kg at the beginning of the chili harvest to approximately Rs. 24/kg at the end of the season.

g. Land Ownership and Tenure

On all four irrigation schemes, complex tenurial arrangements have resulted in the subdivision of lowland and highland allotments. Subdivision of highland and lowland allotments was considered to be one of the most serious problems affecting the well-being of the farm family, water distribution within field channels, and the agricultural productivity of the four irrigation schemes. Approximately 80, 71, 84, and 21 percent of the allotments in the study areas of PSS, Giritale, Minneriya, and Kaudulla, respectively, were subdivided. Furthermore, approximately 52, 46, 20, and 79 percent of the total cultivators in PSS, Giritale, Minneriya, and Kaudulla, respectively, cultivated 1 ac or less within the study areas of these three irrigation schemes.

However, approximately 16, 11, 40, and 52 percent of the cultivators on PSS, Giritale, Minneriya, and Kaudulla, respectively, reported that they had acquired additional lands in other areas of the four irrigation schemes. While this acquisition may bring the acreage cultivated by such households up to the original acreage or perhaps more, these holdings were scattered throughout the area and were not managed as a single unit.

3. Effects of Reduced Agricultural Productivity

In the previous sections, observations and measurements documented the problems of agricultural productivity and the factors which contributed to these problems on the four irrigation schemes. In this

section, the effects of reduced agricultural productivity on the farm families in the four irrigation schemes are discussed.

a. Seasonal Income

Although a number of problems and constraints were encountered with structured interviews of farm families, economic data collected on the four irrigation schemes provided a relative assessment of the economic status of farm families. Economic data collected on PSS and Giritale during 1985 yala provided an estimate of farm family income from paddy and subsidiary crops only. During 1986 yala, economic data collection on Minneriya and Kaudulla was expanded to include all sources of farm family income.

Estimated total seasonal income from all sources on Minneriya and Kaudulla averaged Rs. 8,978 and Rs. 2,445, respectively. (Average seasonal incomes were adjusted to reflect differences in paddy yields reported by cultivators and paddy yields obtained from crop cuttings.) These results indicated that the average farm family on Minneriya earned nearly Rs. 1,500/month during 1986 yala. This income is comparable to the salary and allowances of government clerks and teachers in Sri Lanka. However, most government clerks and teachers also depend on other sources of income. The estimated monthly income of Kaudulla farm families averaged approximately Rs. 400/month. Such low incomes for Kaudulla cultivators were mainly attributed to small farm size (2-ac lowland allotments), low paddy yields, and a lack of off-farm employment opportunities.

Although data used to estimate total seasonal farm family income were not collected on PSS and Giritale, average seasonal income for PSS was probably similar to that estimated for Minneriya. Average seasonal income for Giritale was probably slightly higher than that estimated for Kaudulla, since allotment size on Giritale was 3 ac.

b. Income from Yala Paddy Cultivation

Paddy yields reported by PSS and Giritale cultivators for the 1985 yala averaged 68 bu/ac and 65 bu/ac, respectively. Although some discrepancies in reported paddy yields were observed, the average paddy yields reported by cultivators compared favorably with average paddy yields obtained by crop cuttings. Calculated net returns to farm families for the 1985 yala paddy crop on PSS and Giritale averaged Rs. 657/ac and Rs. 2,213/ac, respectively. High net incomes from paddy cultivation on Giritale were the result of errors made in estimating production costs. These problems were attributed to time and personnel constraints which affected the quality of data collected on Giritale. Average production costs calculated for the other three systems suggested that average net income for yala paddy on Giritale was probably closer to Rs. 450/ac. While calculated net returns for paddy were positive for the majority of farm families on PSS and Giritale, between 35 and 40 percent of the net returns calculated were negative.

Paddy yields reported by Minneriya and Kaudulla cultivators for the 1986 yala averaged 58 bu/ac and 47 bu/ac, respectively. Comparisons of average reported paddy yields with average paddy yields obtained

from crop cuttings suggested that cultivators on Minneriya and Kaudulla under-reported paddy yields by an average of 23 and 16 percent, respectively. When net returns were based on reported paddy yields, an average net loss of Rs. 145/ac and Rs. 953/ac was shown for Minneriya and Kaudulla farm families, respectively. However, by adjusting the average reported paddy yield of Minneriya cultivators to a level which more favorably compares with average paddy yields obtained through crop cuttings, the average net returns from paddy cultivation on Minneriya were about Rs. 900/ac. While calculated net returns for paddy were positive for the majority of farm families on Minneriya, between 25 and 30 percent of the net returns calculated were negative. Similar adjustments on reported paddy yields for Kaudulla still resulted in a average net loss of Rs. 175/ac. In addition, yield data from crop cuttings suggested that net returns from paddy production were negative for 80 to 85 percent of the farm families on Kaudulla.

Perhaps a more meaningful way of evaluating farm family earnings from paddy cultivation is to calculate the returns to family resources. When family labor costs were deducted from production costs, returns to family resources on PSS and Giritale averaged Rs. 1,140/ac and Rs. 850/ac, respectively. (Returns to family resources for Giritale were calculated using an average production cost obtained from the other three irrigation schemes.) Similar calculations for Minneriya and Kaudulla indicated that returns to family resources for Minneriya averaged Rs. 730/ac with reported yields, and approximately Rs. 1,400/ac when yields were adjusted to values obtained from crop cuttings. Returns to family resources for Kaudulla averaged Rs. 15/ac for reported paddy yields, and Rs. 585/ac when yields were adjusted to reflect values obtained from crop cuttings.

Acreages of paddy cultivation reported by PSS, Giritale, Minneriya, and Kaudulla cultivators averaged 4.27, 2.58, 4.27, and 2.01 ac, respectively. Based on the individual averages reported for paddy cultivation on the four irrigation schemes, total seasonal returns to family resources from paddy cultivation averaged Rs. 4,868, Rs. 2,100, Rs. 5,978, and Rs. 1,175 for cultivators on PSS, Giritale, Minneriya, and Kaudulla, respectively. These figures indicated that the average household on PSS and Minneriya earned less than Rs. 1,000/month from paddy cultivation. Similarly, households on Giritale and Kaudulla only earned about Rs. 350/month and Rs. 196/month, respectively, from paddy cultivation.

c. Other Sources of Income

Only 30 percent of the Minneriya farm families reported that paddy cultivation was their only source of yala income. Nearly all of these families reported cultivating paddy on more than 5 ac. Similarly on Kaudulla, where lowland allotments were only 2 ac, only 14 percent of the farm families reported paddy cultivation as their sole source of yala income. Again, nearly all of these families reported cultivating paddy on more than 5 ac.

The majority of farm families on the four irrigation schemes depended on other sources of income to supplement earnings from paddy cultivation. Sources of other income reported by farm families on the four schemes

included tractor rental, subsidiary crops, permanent jobs, pensions, wage labor, personal business, home gardens, and livestock.

Income from Subsidiary Crops. Thirty-five to 45 percent of the soils on the four irrigation schemes are better suited for subsidiary crop cultivation, and profits from subsidiary crops are much greater than those from paddy. However, few cultivators on the four irrigation schemes planted subsidiary crops, thereby limiting agricultural productivity on these lands.

During 1985 yala, only about 4 percent of the PSS study area was cultivated with chili and tobacco. However, calculated net returns for these two crops averaged Rs. 5,330/ac and Rs. 6,700/ac, respectively. Similarly, only about 5 percent of the study area on Giritale was cultivated with chili, tobacco, and groundnuts. However, calculated net returns for these three crops averaged Rs. 5,985/ac, Rs. 7,625/ac, and Rs. 5,420/ac, respectively.

Interviews conducted with cultivators on all four irrigation schemes indicated that most cultivators lacked specific knowledge about the cultivation practices for various subsidiary crops. In addition, cultivators were reluctant to plant subsidiary crops because of the higher investment costs, greater risk of crop failure, theft of produce, and wide fluctuations in market prices.

Other Income. Economic questionnaires developed for Minneriya and Kaudulla provided information on the farm family earnings from sources other than paddy. Gross earnings of Minneriya households from sources other than paddy ranged from zero (11 farm families) to a high of Rs. 110,800 (tractor rental), and averaged Rs. 6,300 during 1986 yala. Similarly, gross earnings of Kaudulla households from sources other than paddy ranged from zero (11 farm families) to a high of Rs. 17,000 (tractor rental), and averaged Rs. 3,060. Economists estimated that yala net incomes for Minneriya and Kaudulla households from sources other than paddy averaged Rs. 3,000 and Rs. 1,200, respectively.

C. RESOURCE CONSERVATION

The four resettlement projects in which these studies were conducted were designed to provide settlers with the land and water resources necessary to sustain an agricultural economy. Each settler was provided a lowland allotment with access to irrigation water and a highland allotment for the homestead (houses were provided on some schemes). In addition, within each irrigation scheme, pasture and forest reservations were set aside for community use. An evaluation of the land use and soil and water resources of the four irrigation schemes follows.

1. Land Use Patterns

On all four irrigation schemes, patterns of land use have changed from the original design due to increased population pressures. Instead of supporting one farm family, approximately 80, 71, 84, and 21 percent of the lowland allotments on PSS, Giritale, Minneriya, and Kaudulla, respectively, now support 2 to 8 farm families. In addition, nearly

all of the lands originally set aside as pasture and forest reservations have been converted to irrigated agriculture. Furthermore, lands set aside as government easement property bordering field channels, drainage channels, and field channel access roads are now under permanent cultivation.

While changes in land use patterns may have increased total crop production for the Polonnaruwa District, the economic well-being and quality of life of the farm family has been reduced. Expansion of the irrigated command area without corresponding improvements in irrigation facilities has increased the demand on a limited water supply. This problem is further aggravated by the cropping pattern, which is essentially a paddy monoculture. As a result, periods of soil moisture stress were observed in nearly all of the study areas in the four irrigation schemes. Periods of soil moisture stress were regarded as one of the major factors affecting paddy yields on all four schemes.

Since the inception of these settlement schemes, criticism has been directed toward the design, planning, and implementation of the homestead allotment. In effect, the highland allotment was expected to function as a gangoda (village garden) similar to those of the Wet Zone, where many of the settlers originated. The highland allotment was intended to provide fruit, vegetables, and grain (for home consumption and sale), pasturage or fodder for livestock, and firewood. Unfortunately, due to geological, hydrological, and biological constraints, the development of these allotments in the resettlement schemes has been a major disappointment. While all of the intended uses may not be possible in all locations, the highland still retains a tremendous potential for production.

Loss of pasture lands to irrigated agriculture has removed livestock as a significant source of income for the settlers on the four irrigation schemes. The few farm families who raise livestock commercially depend on limited pasture lands located outside the irrigation system. However, 60 to 70 percent of the farm families do maintain some livestock for field work and family consumption. These animals are often allowed to roam freely on the highland areas, causing extensive damage to home gardens. In addition, when livestock are tethered on the embankments of channels, they damage canal banks and cross-sectional profiles of the channels.

Conversion of forest reserves to irrigated agriculture has increased the pressure on remaining forests which border the four irrigation systems. Damage to these forests will eventually affect the irrigation system catchment areas. Furthermore, the lack of reasonably convenient sources of firewood has added to the financial burden of farm families on the four irrigation schemes. Interviews of PSS and Giritale farm family women indicated that a substantial portion of farm families on these two schemes travel more than 2 miles for firewood. For these families, firewood is commonly collected every few months or once per season, with several family members traveling to the jungle in a cart. Many of these families must rent bullock or tractor-drawn carts.

2. Soils

Two major soil groups, reddish-brown earths (RBE) and low humic gleys (LHG) were identified in the study areas of the four irrigation schemes. RBE soils were found on the knolls and upper-to-middle slopes of the rolling topography and occupied approximately two-thirds of the irrigated command areas of each scheme. Although these light-textured soils are regarded as good agricultural soils, several physical limitations affect their agricultural use. RBE soils are poorly suited for paddy cultivation because of their low moisture holding capacity and high infiltration rate. RBE soils are structurally weak and, thus, are susceptible to water erosion. Finally, RBE soils located in the middle-to-lower slopes are often subject to high water tables.

The LHG soils were found in the lower slopes and valleys and occupied approximately one-third of the irrigated command areas in each scheme. While LHG soils are good agricultural soils, they have poor drainage characteristics and are susceptible to waterlogging. Because of this, LHG soils are only suited for paddy cultivation. The susceptibility of these soils to waterlogging also exposes them to salinity problems when they are located in areas with poor drainage.

Soils within the study areas of the four irrigation schemes were investigated for chemical and physical characteristics. Observations of crop performance and pH tests were used to indicate soil chemical problems. In addition, plant tissue tests of paddy, soil pH measurements, and observations of fertilizer applications were used as indicators of soil fertility. Evaluation of the physical characteristics of the soils in the study areas of the four irrigation schemes included daily measurements of water table depth and observations of soil erosion.

a. Chemical Characteristics

Field tests of soil pH and observations of crop performance suggested an absence of soil chemical problems in the study areas of the four schemes. However, during reconnaissance investigations of Kaudulla, salinity levels observed in one field channel were high. Although this was an isolated case, it is expected that this may occur elsewhere on LHG soils with drainage problems.

Tissue tests of paddy conducted in the field provided a qualitative estimate of soil fertility. In general, tissue tests indicated high levels of nitrogen and phosphorus and low levels of potassium. High nitrogen levels resulted because cultivators on the four irrigation schemes tended to apply excessive amounts of urea fertilizer. While the new varieties of paddy tolerate excessive nitrogen, overapplication of urea increases production costs and potential groundwater contamination with nitrates.

Soil pH values, which ranged from 6.1 to 7.4, indicated that phosphorus was readily available in both RBE and LHG soils and that it was not necessary to add additional phosphorus to the soils. Soil pH values also suggested that potassium should be readily available in these soils. However, in areas with high rainfall, potassium is easily leached from

the soil profile. Because of this, RBE and LHG soils were probably low in available potassium. Although cultivators overapplied nitrogen fertilizers, they actually underapplied fertilizers containing potassium (V-mixture and TDM). The resulting deficiency in potassium may have contributed to lower paddy yields on all four irrigation schemes.

b. Physical Characteristics

One of the most serious physical problems in RBE soils on the four irrigation schemes was due to elevated, fluctuating water tables. Elevated water tables were associated with paddy cultivation in RBE soils and with seepage losses from the conveyance system. In RBE soils, depth to water table varied significantly with the on and off periods of water deliveries. During on-periods of water deliveries, depth to water table in RBE soils varied from 10 cm to 40 cm below the soil surface. During off-periods of water delivery, depth to water table in RBE soils varied from 40 cm to 110 cm below the soil surface. Elevated water tables pose serious management problems for crops other than paddy. Since the rise in the water table may be largely due to over-irrigation and channel seepage, better water distribution and channel maintenance might alleviate problems associated with high water tables.

Another physical problem observed on the four irrigation schemes was soil erosion. Erosion of soil embankments in the water delivery system was discussed earlier. Soil erosion was also observed in fields planted with subsidiary crops. Subsidiary crops were usually irrigated from small farm channels, rather than from the designed field channels, to better control water applications. However, farm channels were not included in the original design, which uses basin-to-basin irrigation for paddy. As a result, cultivators who plant subsidiary crops excavate temporary farm channels within their fields. These temporary farm channels are often poorly designed and are operated with highly erosive flow rates, resulting in considerable soil loss. While this may not now be a serious problem, any significant increase in subsidiary crop acreage will significantly increase soil erosion problems on the four schemes.

3. Water Quality

During the diagnostic analysis workshop in 1984, several samples of irrigation water and well water from PSS were analyzed for salt content and found to have low salinity. The lack of laboratory facilities prevented the collection of similar data during the field investigations of the four irrigation schemes. However, salinity problems were not observed in crops in the four irrigation schemes, suggesting that the salinity hazard of irrigation water on these four schemes was low.

On the highland, domestic water is primarily obtained from shallow wells. These wells depend on the irrigation system for recharge. When water issues are reduced or curtailed, water levels in the wells drop and the drinking quality of the water is reduced.

Another aspect of water quality is organic and inorganic contamination from agricultural chemicals. The lack of appropriate laboratory

facilities prevented an assessment of organic and inorganic contamination. However, observations of pesticide applications, and measurements and observations of urea applications, suggested that contamination of surface water and groundwater was highly probable. This has serious implications downstream, for domestic water supply, and for agricultural workers who generally obtain their drinking water from small, shallow, hand-dug wells in the fields.

D. FARMER INVOLVEMENT

Many of the management problems that affected operations and maintenance on the four schemes were documented in the water control and agricultural productivity sections of this report. This section of the report specifically covers the involvement of farmers in the management of the four irrigation schemes.

1. Yala Irrigation Schedule

Kanna meetings are intended to represent a joint agreement between the Irrigation Department and the water users concerning allocation procedures at the primary tank level of each scheme. However, the yala irrigation schedules presented at the kanna meetings are prepared by the Irrigation Department without the involvement of water users. Because of this, most cultivators believe that decisions regarding water allocation have already been made and will not be changed. As a result, few cultivators attend the kanna meetings. Although the proceedings are seemingly flexible and allow input by water users, the fact that yala irrigation schedules are prepared in advance by the Irrigation Department may discourage participation and input by the water users. In addition, the format of the kanna meeting does not permit presentation and discussion of the local rotational schedules, which are of major concern to water users. A common complaint by cultivators was that the Irrigation Department assumed that farmers can simultaneously commence and complete various agricultural activities, such as land preparation. Constraints such as availability of labor and cash flow limit the ability of farmers to comply with a fixed irrigation schedule.

Interviews of water users on the four irrigation schemes also indicated that most water users were not opposed to rotational water issues, but were frequently critical of how rotations were decided and supervised. Water users said that even when a rotation was established, influential persons often ask for, and are granted, changes in rotation. From 45 percent to 55 percent of the water users on the four irrigation schemes also reported that no prior notification was given before the distributary channel rotations was changed. For efficient paddy production, cultivators must be able to coordinate inputs such as fertilizers and weedicides with reliable rotation issues.

2. Operation and Maintenance

The Irrigation Department is directly responsible for operation and maintenance of the four irrigation schemes. Overall supervision of operation and maintenance is the responsibility of the irrigation engineer within each system. The irrigation engineer is supported by technical

assistants, who communicate with the irrigation engineer concerning irrigation demands and system performance. Technical assistants are supported by patrol laborers and work supervisors. In general, patrol laborers are responsible for opening and closing distributary channel headgates, and work supervisors are responsible for maintenance activities throughout the conveyance system.

Traditionally, management of water deliveries below the distributary channel has been the responsibility of a locally elected vel vidane. In addition, the vel vidane supervises the cleaning of field channels and may assist the work supervisor in organizing crews for cleaning distributary channels. Although the vel vidane is elected and paid by the water users, he is also responsible to the colonization officer in the Agrarian Services Department. As a result, the vel vidane's allegiance is divided between the water users and the government. In addition, many of the responsibilities of the vel vidane have been transferred to these politically appointed colonization officers. The vel vidane's position has been further confused by the introduction of the project committee system, which is attempting to organize water users for more effective participation in irrigation system management. At the field channel level, the project committee system created the ela nivoijitha, a locally elected water user responsible for representing the field channel group at the distributary channel level. Sometimes the ela nivoijitha and the vel vidane are the same person. When they are not, confusion about their roles and responsibilities exists.

When respondents were asked about maintenance of the irrigation scheme, the majority responded that Irrigation Department officers were responsible for maintenance at, or above, the distributary channel level. Most respondents viewed the maintenance of the field channel as a farmer responsibility. The Irrigation Department expects that farmers will assume responsibility for cleaning the field channel below the field channel headgate. This request is made formally at the kanna meeting, and fines can be levied on farmers who do not comply. While the Irrigation Department and the vel vidane legally have the ability to enforce this request, it is very difficult to do in actuality. Again, constraints in funding and personnel, plus the community's desire to avoid involvement by the district police and courts, severely restricts enforcement.

Maintenance at the field channel level is further complicated by the various temporary or short-term tenure arrangements that are common on all four irrigation schemes. While the land owner may assume that maintenance of the field channel is the responsibility of the lessee, short-term lessees have little interest in field channel maintenance.

Confusion among farmers concerning their responsibilities for field channel maintenance has also increased with the introduction of operation and maintenance (O&M) fees. Although the fee was meant to support maintenance and repair work, many farmers believed that the O&M fees covered regular cleaning and repair of the field channels by Irrigation Department personnel.

Inadequate maintenance was identified by cultivators as a major problem on all four irrigation schemes. Although water users blamed

the Irrigation Department for inadequate maintenance, they also recognized that tractors, buffalo, and illegal cutting of channel banks contributed to maintenance problems.

3. Project Committee System

In 1984 the Irrigation Management Division (IMD) of the Ministry of Lands and Land Development initiated a new program to involve district departments and water users in the management of major irrigation schemes. One of the major tasks of this new program was to organize water users at the field channel (field channel group), distributary channel (project subcommittee), and irrigation scheme (project committee) level for more effective participation of water users in operation and maintenance.

The project committee is chaired by a project manager appointed by the IMD. Other members of the project committee include the irrigation engineer responsible for the scheme, an agriculture officer, and a colonization officer. Initial responsibilities of the project committee included collecting O&M fees from the water users and coordinating maintenance work with the Irrigation Department. Over time it is expected that the project committee will become involved with planning and managing water deliveries in each of the schemes, but is not currently involved in these activities.

While this program has potential for improving the overall management of major irrigation schemes, the newly created IMD was not provided with the personnel and resources needed to effectively implement this program. During these investigations, the IMD was able to retain project managers for little more than a year on PSS and Giritale. Project managers on Minneriya and Kaudulla remained less than six months. As a result, the project committee system was only partially implemented on PSS and Giritale and was essentially non-existent on Minneriya and Kaudulla. This was reflected in the poor level of knowledge exhibited by water users concerning the project committee system. Approximately 63 percent of the PSS water users and 79 percent of the Giritale water users were aware of the project committee system. However, less than one-third of the Minneriya and Kaudulla cultivators were aware of the project committee system.

Ineffective implementation of the project committee system has resulted in confusion about the project committee's objectives, functions, and composition. Approximately 74 percent of the PSS water users did not know how the subcommittee president (distributary channel representative) was selected, and most water users thought that the field channel representative was appointed rather than elected. In addition, from 60 to 76 percent of the PSS water users erroneously believed that the major function of the project committee system was to settle disputes and decide rotation schedules.

Water user confidence in the project committee system was also eroded by the cumbersome procedures used in the allocation of O&M funds for maintenance. During 1985 yala, approximately 57 percent and 74 percent of the sample cultivators on PSS and Giritale, respectively, paid O&M fees. Less than 20 percent of the PSS and Giritale cultivators

reported paying O&M fees in 1986 yala. Similarly, on Minneriya and Kaudulla, approximately half of the sampled cultivators paid O&M fees in 1985 yala, while less than 15 percent of these cultivators indicated payment of O&M fees in 1986 yala. The reasons given for non-payment included inadequate knowledge of how the money would be spent, fear that maintenance funds would not be allocated to their area, poor supervision of maintenance work, no punishment for non-payment, personal financial difficulties, and belief that the amount of the fee was excessive.

Despite the fact that the project committee system has been poorly implemented, from 74 percent to 91 percent of the water users on the four irrigation schemes expressed strong interest in the development of water user associations that would be responsible for water allocation and maintenance. In addition, many water users on the four irrigation schemes indicated a willingness to pay O&M fees, provided that at least half of the fee was allotted to maintenance within the local area. Informal interviews of vel vidanes on PSS generally supported the comments of water users about O&M fees. Vel vidanes indicated that water users would likely pay O&M fees if the money was spent within their distributary channels, if maintenance funds were allocated within a reasonable time, and if the supervision of repair work was improved.

IV. SUMMARY OF FINDINGS AND RECOMMENDATIONS

A. SUMMARY OF FINDINGS

Interdisciplinary baseline investigations were conducted on Parakrama Samudra and Giritale irrigation schemes during the 1985 yala and on Minneriya and Kaudulla irrigation schemes during the 1986 yala. The findings of the diagnostic analysis relating to water control, agricultural productivity, resource conservation, and farmer involvement are summarized below.

1. Water Control

Three performance parameters of water control were used to evaluate water control on the Parakrama Samudra, Minneriya, and Kaudulla irrigation schemes: adequacy, equity and reliability of water supply. Although personnel problems limited the amount of water measurement data collected on Giritale, observations supplemented with a few water measurements suggested that the physical performance of Giritale was similar to the other three irrigation schemes.

The overall, weekly average water supply measured for PSS (D1 main canal), Minneriya (Yoda Ela), and Kaudulla (Stage I and Stage II) was 10.3, 10.7, and 12.5 mm/day, respectively. Based on the Irrigation Department design of 37.5 ac/cfs (16.4 mm/day), the overall, weekly average water supply was inadequate on all three irrigation schemes. More importantly, measured weekly average water supply did not meet the calculated water demands of the irrigated command areas of the four irrigation schemes.

A high degree of spatial variability in water supplied to distributary channels, field channels, and allotments existed on all four irrigation schemes. Average weekly water supply to distributary channels on the four irrigation schemes varied from less than 5 mm/day to greater than 35 mm/day. Similar variations in water supply to field channels and allotments were found. With the exception of PSS, where water delivery was restricted by an aqueduct located below RB7 on the D1 north main canal, there was no apparent pattern of inequitable water supply on the four irrigation schemes.

Although planned water delivery schedules existed for each scheme, the Irrigation Department was unable to implement the schedules according to plan. Continuous water issues for land preparation were extended by 2 to 2-1/2 weeks on all four irrigation schemes, and unannounced changes in rotational water issues were common on all four irrigation schemes. Furthermore, substantial fluctuations in flow rates within and between issue periods were measured in distributary channels, field channels, and allotments on all four irrigation schemes.

Domestic water from highland wells was also affected by water delivery on all four irrigation schemes. During extended periods of canal

closure, highland wells became inadequate, unreliable, and unpalatable sources of domestic water.

Factors which contributed to inadequate, inequitable, and unreliable water supply on the four irrigation schemes included inadequate main canal carrying capacities, excessive expansion of the irrigated command areas, inappropriate hydraulic and measuring structures required to implement and monitor operational plans, inadequate maintenance, inadequate enforcement of irrigation rules and regulations, and unsatisfactory involvement of water users in operation and maintenance.

Effects of inadequate water control included low productivity of paddy, increased illegal access of water from drainage and conveyance systems, and an increase in disputes and conflicts over water. In addition, inadequate water control also affected crop management decisions by cultivators concerning crop and variety selection, planting methods, and weed control practices.

2. Agricultural Productivity

Data collected during the diagnostic analysis was used to evaluate the agricultural productivity of the irrigated command areas and the highland homesteads of the four irrigation schemes. Three performance parameters of agricultural productivity were evaluated: cropping intensity, cropping patterns, and yala paddy crop yields.

Within the study sites of the four schemes, irrigated cropping intensities ranged from 95 percent (Minneriya) to 99 percent (Giritale). Although yala cropping intensities on the four irrigation schemes were relatively high, cropping patterns were essentially paddy monocultures. Yala paddy accounted for approximately 96, 95, 96, and 91 percent of the irrigated cropped areas of PSS, Giritale, Minneriya, and Kaudulla, respectively. Irrigated subsidiary crops cultivated on the four schemes were primarily chili, tobacco, pulses, and very small areas of vegetables grown on threshing floors and paddy field bunds.

According to the Agriculture Department, the new varieties of paddy have potential grain yields of 140 bu/ac when grown under optimum conditions. However, under normal field conditions, average potential yala paddy yields should range between 120 and 130 bu/ac. Paddy yields obtained from crop cutting surveys conducted on PSS and Giritale during 1985 yala and on Minneriya and Kaudulla during the 1986 yala only averaged 90, 88, 93, and 67 bu/ac, respectively.

Although average yala paddy yields on PSS, Giritale, and Minneriya were above those obtained on most irrigation schemes in Sri Lanka, they were substantially lower than the potential. The fact that yala paddy yields on Kaudulla were significantly lower than those of the other three systems indicated that production constraints were more serious on this scheme. In addition, paddy yields varied considerably within and between study sites on the four irrigation schemes. Coefficients of variation in paddy yields ranged from 40 to 260 percent on PSS, 30 to 120 percent on Giritale and Minneriya, and 20 to 180 percent on Kaudulla.

In general, cropping intensities on the highland homesteads were low on all four irrigation schemes. Interviews of farm family women indicated that from 4 percent of the highlands of PSS to 25 percent of the highlands of Kaudulla were located in areas where rock outcroppings and shallow soils prevented the cultivation of crops. Permanent tree crops were cultivated on 96, 100, 92, and 75 percent of the respective highland homesteads of PSS, Giritale, Minneriya, and Kaudulla. However, highland gardens were only grown on approximately 29, 28, 29, and 38 percent of the respective highland homesteads of these four schemes. The size of most highland gardens was limited due to insufficient rainfall and the absence of irrigation water. Interviews indicated that a highland crop was grown on 20 to 30 percent of the highland homesteads where water from a nearby irrigation channel could be accessed.

Inadequate water control was identified as a major factor affecting the agricultural productivity of the lowland allotments on the four irrigation schemes. In addition, agricultural productivity of the lowland allotment was also affected by inappropriate cropping patterns; poor seed quality; inefficient use of fertilizers, insecticides and herbicides; inadequate extension of agricultural information; inadequate access to agricultural credit; and complex tenurial arrangements, which resulted in subdivision of highland and lowland allotments. Also, inadequate crop price control, storage facilities, and marketing facilities for subsidiary crops further reduced the potential agricultural productivity of the area.

Reduced agricultural productivity on the four irrigation schemes resulted in low seasonal incomes. Estimated total yala seasonal incomes on Minneriya and Kaudulla averaged only Rs. 8,978 and Rs. 2,445, respectively. Average yala seasonal incomes of Minneriya cultivators were comparable with the salary and allowances of government clerks and teachers. However, most government employees also depend on other sources of income. Low incomes for Kaudulla farm families were mainly attributed to small farm size (2-ac lowland allotments), low paddy yields, and a lack of off-farm employment opportunities.

While only yala cropping incomes were collected for PSS and Giritale, total seasonal incomes of PSS were probably similar to those calculated for Minneriya, while total yala seasonal incomes of Giritale were estimated slightly higher than those calculated for Kaudulla.

Returns to family resources from paddy cultivation on PSS, Giritale, Minneriya, and Kaudulla only averaged Rs. 1,140, Rs. 850, Rs. 1,400, and Rs. 585 per acre, respectively, when yields were estimated from crop cuttings. Acreages of paddy cultivation reported by PSS, Giritale, Minneriya, and Kaudulla cultivators averaged 4.27, 2.58, 4.27, and 2.01 acres, respectively. Based on the individual averages reported for paddy cultivation on the four irrigation schemes, total seasonal returns to family resources from paddy cultivation averaged Rs. 4,868, Rs. 2,100, Rs. 5,978, and Rs. 1,175 for PSS, Giritale, Minneriya, and Kaudulla, respectively. These figures indicated that the average PSS and Minneriya households earned less than Rs. 1,000/month from paddy cultivation. Similarly, Giritale and Kaudulla households only earned an average of

approximately Rs. 350/month and Rs. 196/month, respectively, from paddy cultivation.

Because incomes from paddy cultivation were insufficient, a majority of farm families on all four irrigation schemes depended on other sources of income to supplement earnings from paddy cultivation. Sources of other income reported by farm families on the four schemes included tractor rental, subsidiary crops, permanent jobs, pensions, wage labor, personal business, home gardens, and livestock. Of these, wage labor was the most common source of additional income. Only a few cultivators on the four irrigation schemes cultivated subsidiary crops. However, average returns to family resources from subsidiary crop cultivation was 3 to 4 times that calculated for paddy cultivation. Overall estimates of net income from other sources averaged Rs. 3,000 and Rs. 1,200 for Minneriya and Kaudulla, respectively. Similar data were not collected on PSS and Giritale.

3. Resource Conservation

The four resettlement projects in which these studies were conducted were designed to provide settlers with the land and water resources necessary to sustain an agricultural economy. However, over time, patterns of land use have changed from the original design due to increased population pressures. Instead of supporting one farm family, approximately 80, 71, 84, and 21 percent of the lowland allotments on PSS, Giritale, Minneriya, and Kaudulla, respectively, now support 2 to 8 farm families. In addition, nearly all of the lands originally set aside as pasture, forest reservations, and government easement property bordering field channels, drainage channels, and field channel access roads have been converted to irrigated agriculture. While changes in land use patterns may have increased total crop production for the Polonnaruwa District, the economic well-being and quality of life of the farm family has been reduced.

Expansion of the irrigated command without corresponding improvements in irrigation facilities was regarded as a major factor affecting water control. This problem was further aggravated by a cropping pattern that remains essentially a paddy monoculture. Cultivation of pasture lands has removed livestock as a significant source of income for settlers on the four irrigation schemes. In addition, homestead gardens, field crops, and irrigation facilities are constantly damaged by the few livestock that families maintain for field work and family consumption. Conversion of forest reserves to irrigated agriculture has removed convenient sources of firewood and increased pressure on the remaining forest watersheds bordering the irrigation schemes. Furthermore, the potential of the highland allotment, which was originally envisioned to function as a gangoda (village garden) similar to those of the Wet Zone, has never been realized due to geological, hydrological, and biological constraints.

The only chemical problems found with soils in the four irrigation schemes were isolated pockets of salinity that occurred in areas with extremely poor drainage. However, elevated water tables in the reddish-brown earth soils posed serious management problems for crops other

than paddy on all four irrigation schemes. The cultivation of paddy in RBE soils was regarded as a major contributing factor of elevated water tables. Another physical problem observed on the four irrigation schemes was soil erosion. Erosion of soil embankments within the water delivery system resulted from overloading the canals. In addition, soil erosion was also observed in fields planted with subsidiary crops. This erosion resulted from improper design and construction of farm channels within the fields. While this may not now be a serious problem, soil erosion will increase as the acreage of subsidiary crops increases.

Electroconductivity analysis of a limited number of irrigation water and drainage water samples indicated a low salinity hazard. However, observations of pesticide applications, and measurements and observations of urea applications, suggested that organic and inorganic contamination of surface water was highly possible. This has serious implications downstream for domestic water supply and for agricultural workers, who generally obtain their drinking water from small, shallow, hand-dug wells in the fields.

4. Farmer Involvement

Kanna meetings are intended to represent a joint agreement between the Irrigation Department and water users concerning allocation procedures at the primary tank level of each scheme. However, the yala irrigation schedules are prepared in advance of the kanna meeting without involvement of the water users. In addition, the format of the kanna meeting does not permit presentation and discussion of the local rotation schedules that are of major concern to the water users. As a result, most cultivators believe that the schedule is fixed, and they are not interested in participating in the meeting.

Although water users were not opposed to rotational water issues, they were frequently critical of how rotations were decided and supervised. From 45 to 55 percent of the water users on the four irrigation schemes reported that no prior notification was given before changing distributary channel rotations.

Traditionally, management of water deliveries below the distributary channel has been the responsibility of a locally elected vel vidane. However, the role of the vel vidane in water management has been confused by past governmental decisions and more recently by the introduction of the project committee system.

Although water users are requested to clean field channels and most cultivators viewed cleaning the field channel as a farmer responsibility, current methods of enforcing field channel cleaning are ineffective. Problems with maintaining field channels are further complicated by the various temporary or short-term tenure arrangements that are common on all four irrigation schemes. Furthermore, many water users believed that O&M fees covered regular cleaning and repair of field channels by Irrigation Department personnel.

The project committee system was implemented without proper institutional support. As a result, the project committee system was only

partially implemented on PSS and Giritale and was essentially non-existent on Minneriya and Kaudulla. This was reflected in the poor level of knowledge exhibited by water users concerning the project committee system. Approximately 63 percent of the PSS water users and 79 percent of the Giritale water users were aware of the project committee system. However, less than one-third of the Minneriya and Kaudulla water users were aware of the project committee system. Approximately two-thirds of the PSS cultivators who were aware of the project committee system erroneously believed that the major function of the project committee system was to settle disputes and decide rotation schedules.

Water users' confidence in the project committee system was also eroded by the cumbersome procedures used in the allocation of O&M funds for maintenance. As a result, only 15 to 20 percent of the water users on the four schemes paid O&M fees during 1986 yala.

Despite the fact that the project committee system has been poorly implemented, 74 to 91 percent of the water users on the four schemes expressed strong interest in the development of water users associations that would be responsible for water allocation and maintenance. In addition, many water users on the four schemes indicated a willingness to pay O&M fees, provided that at least half of the fee was allocated to maintenance within the local area. In addition, vel vidanes on PSS indicated that water users would be likely to pay O&M fees if maintenance funds were allocated within a reasonable time, if they were spent within their distributary channels, and if supervision of repair work improved.

B. RECOMMENDATIONS

The following recommendations are based on the findings of the baseline investigations of four irrigation schemes in the Polonnaruwa District.

1. Water Control

a. Management Plan for Tank Water Supplies

A plan for the management of water supplies for the four irrigation schemes needs to be developed. The plan should include projected runoff from surrounding watersheds, water supplied by Mahaweli diversions, estimated conveyance and storage losses, and the actual command acreage of each system. The plan should project an average, expected water supply for each tank to supply a planned demand. The plan should recognize the operational interdependence of the four irrigation schemes.

b. Water Delivery Management Plan

Water delivery management plans for yala and maha irrigation seasons should be drafted for each of the four irrigation schemes. The plans should be based on the proposed structural improvements, account for variations in soil type, have sufficient flexibility to account for changes in cropping patterns, and ensure adequate domestic water supplies between irrigation seasons. The plan should project required water deliveries throughout the command area. In addition, the management

plan should include alternative strategies for water supply during periods of drought and incorporate a monitoring and evaluation plan so that the water control performance of each scheme can be maintained and improved. If rotational water deliveries are required, it is recommended that the Irrigation Department implement rotations at the field channel level. Farmer involvement in the development of water delivery management plans is considered essential.

c. Restoration of the Conveyance Systems

Basic to the development of a water delivery management plan is the restoration of the conveyance system of each scheme. This will require that all main canals, branch canals, distributary channels, and field channels be brought to adequate capacity. The capacity of main canals will require the installation of rip-rap at points where severe erosion of canal banks exists. Repair of existing hydraulic structures and installation of new structures will be necessary to assure appropriate water control throughout each scheme. In addition, installation of measuring devices or calibration of control structures is required for monitoring water deliveries. Consideration should be given as to how these devices will be used in the management plan of the system. Decisions should be made as to the most suitable types and location of these devices, given the proposed delivery schedule.

Several preliminary steps are required to restore the conveyance systems. First, engineering surveys of the conveyance systems are needed to establish the current cross-sectional and longitudinal profiles and to determine the extent of restoration required. During these surveys, all of the hydraulic structures should be evaluated for condition and adequacy in providing water control.

An adequate capacity for conveyance systems depends upon the irrigated area. Therefore, the irrigated command areas of main channels, branch channels, distributary channels, and field channels need to be determined in order to plan water deliveries. Irrigated command areas can be determined by engineering surveys or by standard aerial photographic interpretation methods. Of the two methods, aerial photographic interpretation is more cost effective. More importantly, aerial photographic interpretation would provide an opportunity to produce detailed maps of all subcommand areas for potential use in geographic information systems.

The required capacity for the system also depends on the types and distribution of soils in the irrigated command area. Therefore, soil surveys of the irrigated command acreages are needed in order to plan water deliveries.

d. Further Field Investigations

The development of an effective operational plan for each irrigation scheme will require detailed investigation of available water resources and conveyance and on-farm water losses. An evaluation of seasonal water supply to the four tanks is required in order to develop a management plan for tank water supply. Operational plans for water delivery

will also require additional studies on conveyance losses. In addition, further investigations of seepage, deep percolation, and leakage from paddy fields should be quantified for the major soil types.

Hydrological investigations of the highland homestead areas in the four irrigation schemes should be conducted to determine the potential of groundwater resources. In addition, investigations should be conducted to determine the feasibility of providing highland areas with direct access to irrigation water for crop production.

e. Water Users Associations

The formation of effective water users associations based on the project committee system is critical to successful operation and maintenance of each scheme. However, to be effective, water users associations must be fully integrated into the development and implementation of the operation and maintenance plan for each system. In addition, water users associations should have the authority to raise funds, contract maintenance and minor construction work, and hire a separate manager for water delivery to field channels along distributary channels. To prevent mismanagement, these associations should have formal charters and by-laws that not only define their responsibilities, but provide water users' associations with authority to punish individuals who violate irrigation rules and regulations.

f. Water-Related Courts

A system to deal exclusively with water-related court issues is needed to ensure enforcement of the Irrigation Ordinance. Currently, infractions are not pursued in the civil court system because of lengthy and costly court procedures.

2. Agricultural Production

In addition to water control, several other constraints which now limit agricultural productivity on all four irrigation schemes were identified. These constraints are addressed by the following recommendations.

a. Crop Diversification

Crop diversification is essential for improving the agricultural productivity of reddish-brown earth soils, and for increasing yala incomes on all four irrigation schemes. Incentives needed to increase crop diversification on the four irrigation schemes include government-guaranteed, fair prices for produce, additional storage and marketing facilities, and improved agricultural extension of information concerning the cultivation practices of subsidiary crops.

While diversification of yala cropping patterns would improve the agricultural productivity of reddish-brown earth soils, it may alter current patterns of water demand. Changes in water demand may increase the complexity of water delivery on all four irrigation schemes. Another potential problem of crop diversification may be the increased loss of

soil from farm channels constructed within and between *liyaddas*. A solution to this problem would be to provide cultivators with assistance and information on flow rates and farm channel designs which minimize soil erosion.

b. Agricultural Inputs and Extension

The Certified Seed Division of the Agriculture Department needs to improve the quality of certified seed sold to cultivators. Currently, cultivators prefer to use their own seed or seed of their neighbors due to the poor quality of certified seed.

The Agriculture Department should review its current fertilizer recommendations for paddy. During the review, particular attention should be paid to simplifying fertilizer recommendations for paddy. In addition, the Agriculture Department should consider changing fertilizer recommendations to reflect differences in soil type, and evaluate the necessity of phosphorus applications. The Agriculture Department could also instruct cultivators about the composition of local fertilizers and teach simple calculations concerning fertilizer applications.

Greater emphasis on the proper use and potential health hazards of herbicides and pesticides is needed on all four irrigation schemes. Observations and interviews of farm families on the four irrigation schemes indicated that local individuals do contract spraying. These individuals should be provided with special training in sprayer application of agro-chemicals.

The current agricultural extension system appears inadequate to address the needs of all of the farm families on the four irrigation schemes. However, nearly every farm family interviewed on the four irrigation schemes had at least one family member who could read a newspaper. Furthermore, farm families on all four irrigation schemes expressed interest in obtaining information on new paddy varieties, pests, diseases, weed control, subsidiary crops, water management, agro-chemicals, and animal husbandry. High literacy rates and desire to obtain relevant agricultural information suggests that the Agricultural Extension Service could place a greater emphasis on the publication and distribution of extension bulletins, newsletters, and pamphlets, and increase the use of radio and newspapers.

Finally, agricultural extension agents should work directly with women concerning the cultivation of paddy, subsidiary crops, home gardening, livestock, and permanent tree crops. Much of this work should be centered on the highland homesteads, which are under-utilized.

c. Agricultural Credit

Many farm families are excluded from institutional credit because they lack land titleship. This should be provided to descendants of original settlers. In addition, the government should officially recognize families who have settled on reserved lands later sanctioned for irrigation by providing them with titles to the land. In addition,

lending institutions must become more convenient, flexible, and reduce the amount of paperwork required for agricultural loans.

d. Storage and Marketing

The government policy and program for storage and marketing of paddy has had a positive influence on commercial paddy production. Similar policies and programs for storage and marketing of subsidiary crops are needed to stimulate crop diversification.

e. Further Field Investigations

More detailed baseline information on the cultivation and profitability of subsidiary crops, vegetables, and permanent tree crops is needed. Information provided by these studies would benefit efforts to improve the agricultural productivity of both lowland and highland allotments on all four irrigation schemes.

Crop diversification efforts also need to be supported by farmer-managed field trials and farmer-managed demonstrations (on both highland and lowland allotments). Such trials would enable the Agriculture Department to monitor variations in farm management practices, and identify production constraints that may not exist on agricultural research stations.

3. Additional Institutional Involvement

a. Government Employees

Government employees, particularly field officers, need to be provided with adequate housing, work facilities, and transportation. In addition, better schooling and health care facilities are necessary to attract and hold career employees in remote locations. The performance of government employees is also hindered by cumbersome bureaucratic procedures and regulations which often delay decision-making. Bureaucratic procedures and regulations need to be evaluated and streamlined.

b. Private Sector Development

The government should increase off-farm employment opportunities through projects and programs that encourage development of the private sector. Small agro-industries and services related to agriculture would provide much needed off-farm employment opportunities. Increased population pressures on settlement lands and the lack of off-farm employment opportunities were regarded as major factors that contributed to subdivision of allotments, subsistence-level agriculture, and decreased well-being of farm families on all four irrigation schemes.

V. LITERATURE CITED

Alwis, J. et al. 1983a. System H of the Mahaweli Development Project, Sri Lanka: 1982 diagnostic analysis. WMS Report 16. Water Management Synthesis II Project, Colorado State University, Fort Collins.

Alwis, J. et al. 1983b. The Rajangana Scheme, Sri Lanka: 1982 diagnostic analysis. WMS Report 19. Water Management Synthesis II Project, Colorado State University, Fort Collins.

Jayewardene, J.; Kilkelly, M.K. 1983. System H of the Mahaweli Development Project, Sri Lanka: 1983 diagnostic analysis. WMS Report 20. Water Management Synthesis II Project, Colorado State University, Fort Collins.

Martin, T.C. 1988. Irrigated Land Use and Irrigation distribution systems of four schemes in Polonnaruwa District of Sri Lanka. WMS Report 77. Water Management Synthesis II Project, Colorado State University, Fort Collins.

Skogerboe, G.V.; Brewer, J.D.; Brown, F.B.; Early, A.C.; McConnen, R.J. 1984. Irrigation Systems Management Project design report, Sri Lanka. WMS Report 33. Water Management Synthesis II Project, Colorado State University, Fort Collins.

Water Management Synthesis II Project. 1983. Diagnostic analysis of irrigation systems, Volumes 1 and 2. Colorado State University, Fort Collins.

VI. GLOSSARY OF ABBREVIATIONS AND TERMS

ac	acre
bu	bushel
cfs	cubic feet per second; cusec
cm	centimeter
D-channel	distributary channel
ela niyojitha	field channel representative
ET	evapotranspiration
F-channel	field channel
FIR	field irrigation requirement
gangoda	village garden
IMD	Irrigation Management Division
ISM	Irrigation Systems Management Project
Kachcheri	district government agent's office
kanna	precultivation
kg	kilogram
km	kilometer
KVS	agricultural field extension officer
LHG	low, humic gley (soil)
liyadda	small, bunded portion of a field
maha	wet season; mid-October to late March
MLLD	Ministry of Lands and Land Development
mm	millimeter
MSS	multi-spectral scanner
O&M	operation and maintenance

pH	measure of acidity or alkalinity of soil
PSS	Parakrama Samudra Scheme
RBE	reddish-brown earth (soil)
Rs.	rupees
TDM	top dressing mixture (fertilizer)
USAID	United States Agency for International Development
vel vidane	government-appointed farmer representative responsible for D-channel operation; usually a farmer
WMS	Water Management Synthesis Project
yala	dry season; mid-April to late September