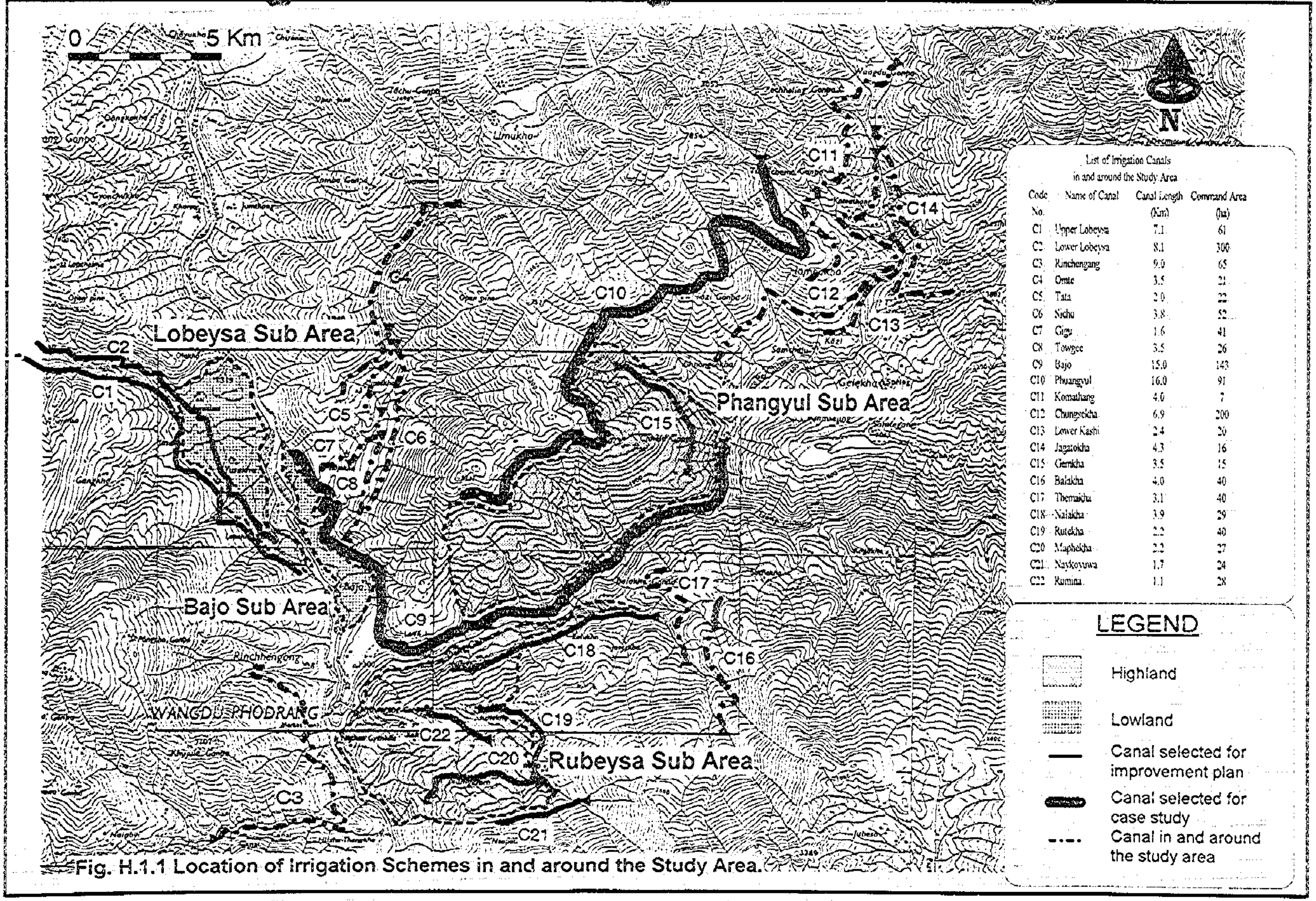
APPENDIX H
FIGURES



List of Irrigation Canals in and around the Study Area

Code No.	Name of Canal	Canal Length (Km)	Command Area (ha)
C1	Upper Lobeysa	7.1	61
C2	Lower Lobeysa	8.1	300
C3	Rinchengang	9.0	65
C4	Omte	3.5	21
C5	Tata	2.0	22
C6	Sichu	3.8	52
C7	Gigu	1.6	41
C8	Towgee	3.5	26
C9	Bajo	15.0	143
C10	Phuangyul	16.0	91
C11	Komathang	4.0	7
C12	Chungsekha	6.9	200
C13	Lower Kashi	2.4	20
C14	Jagatokha	4.3	16
C15	Gemkha	3.5	15
C16	Balakha	4.0	40
C17	Themakha	3.1	40
C18	Nalakha	3.9	29
C19	Rutekha	2.2	40
C20	Maphekha	2.2	27
C21	Naykoyuwa	1.7	24
C22	Rumina	1.1	28

Fig. H.1.1 Location of Irrigation Schemes in and around the Study Area.

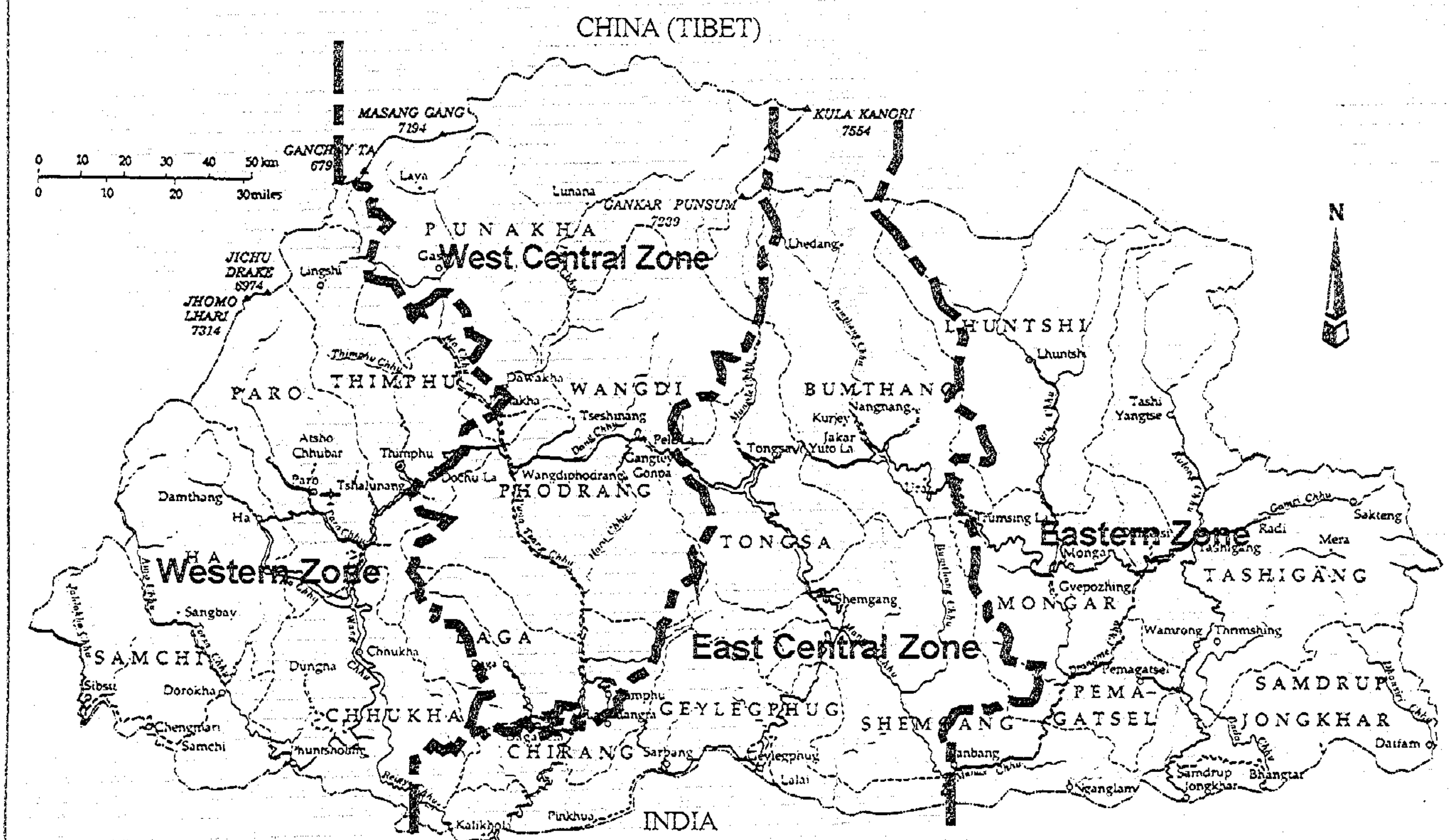


Fig. H.2.1 Four Zones of Bhutan

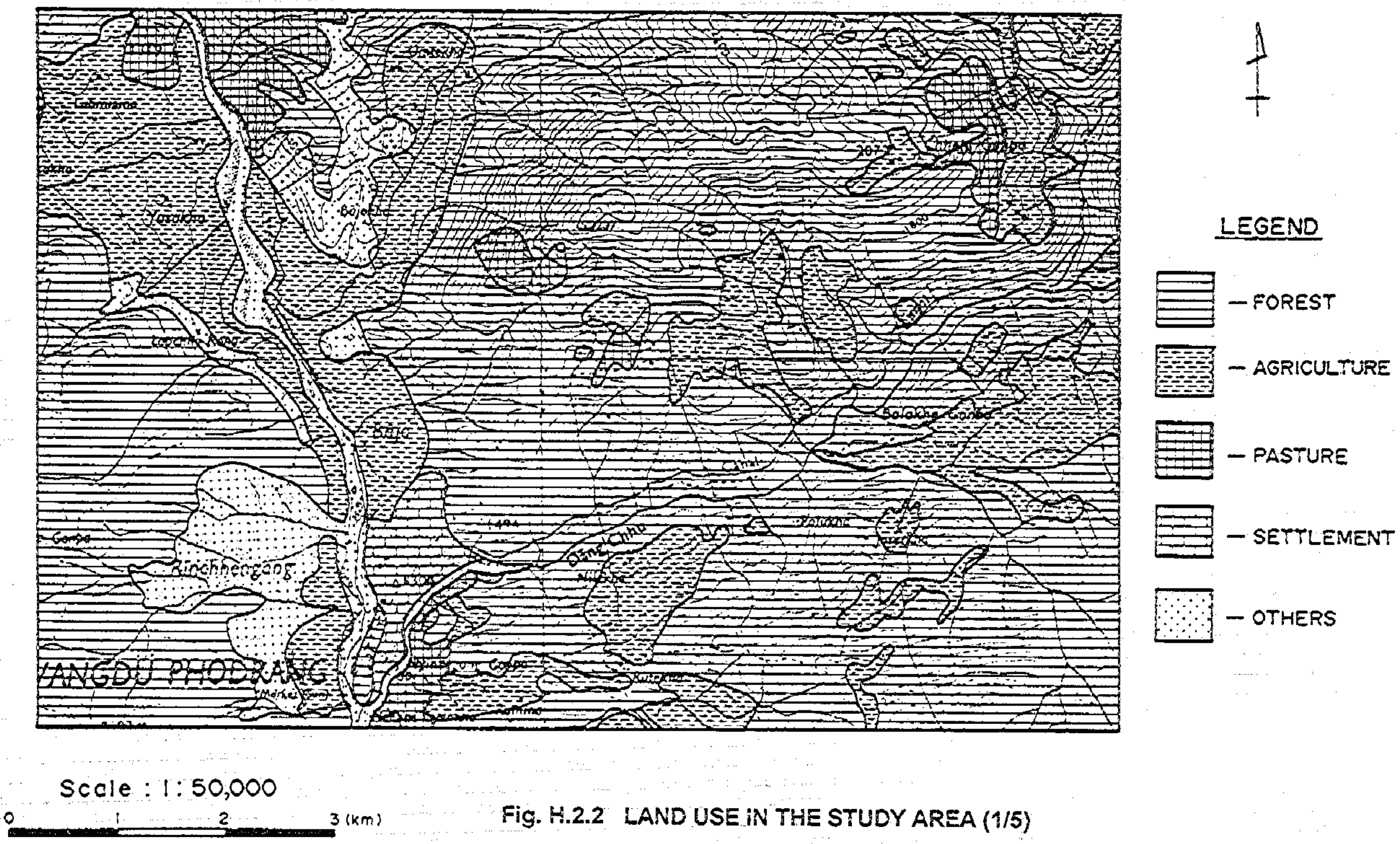


Fig. H.2.2 LAND USE IN THE STUDY AREA (1/5)

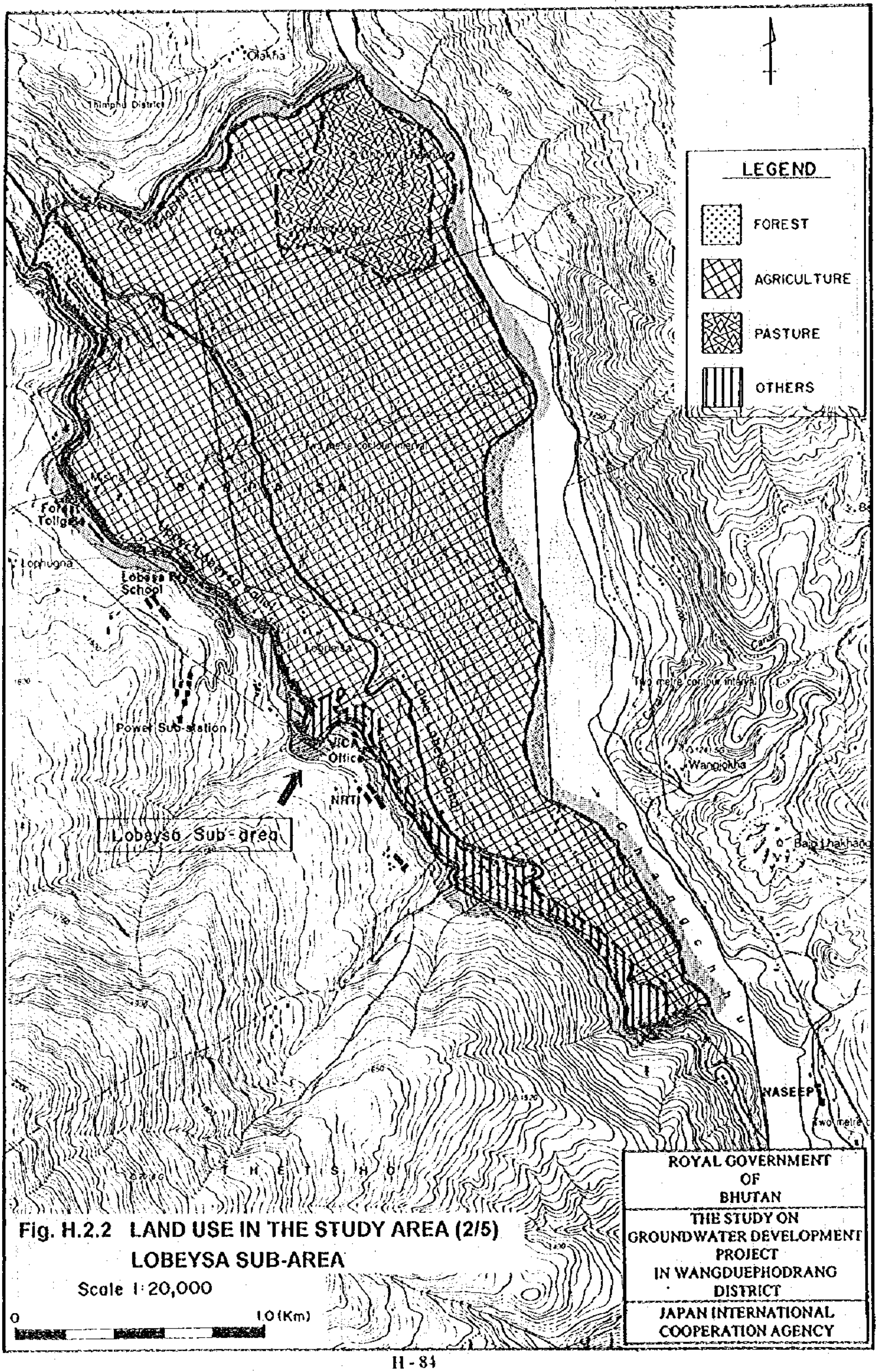


Fig. H.2.2 LAND USE IN THE STUDY AREA (2/5)
LOBEYSA SUB-AREA

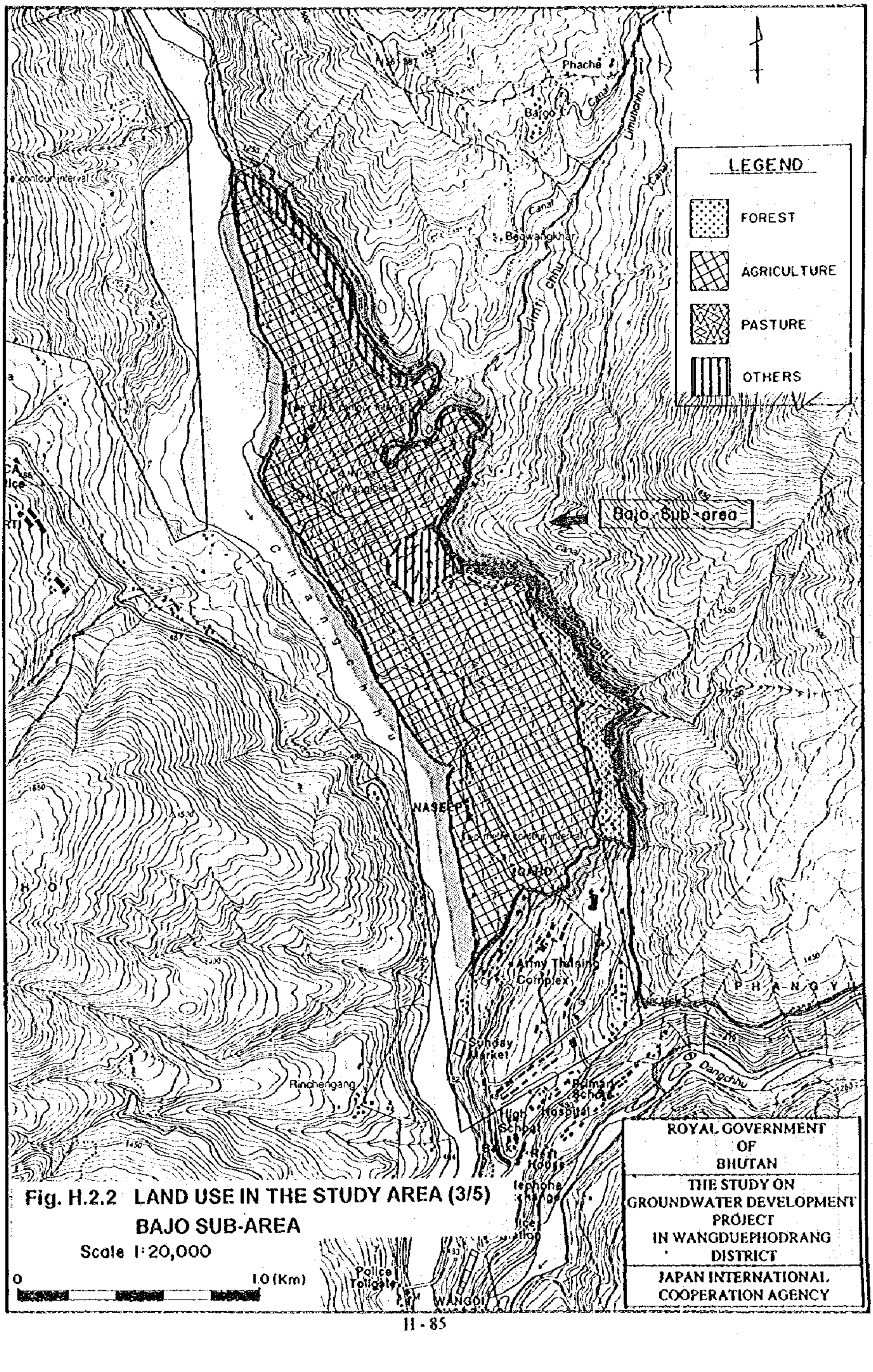


Fig. H.2.2 LAND USE IN THE STUDY AREA (3/5)
BAJO SUB-AREA
Scale 1:20,000
0 1.0 (Km)

ROYAL GOVERNMENT OF BHUTAN

THE STUDY ON GROUNDWATER DEVELOPMENT PROJECT IN WANGDUEPHODRANG DISTRICT

JAPAN INTERNATIONAL COOPERATION AGENCY

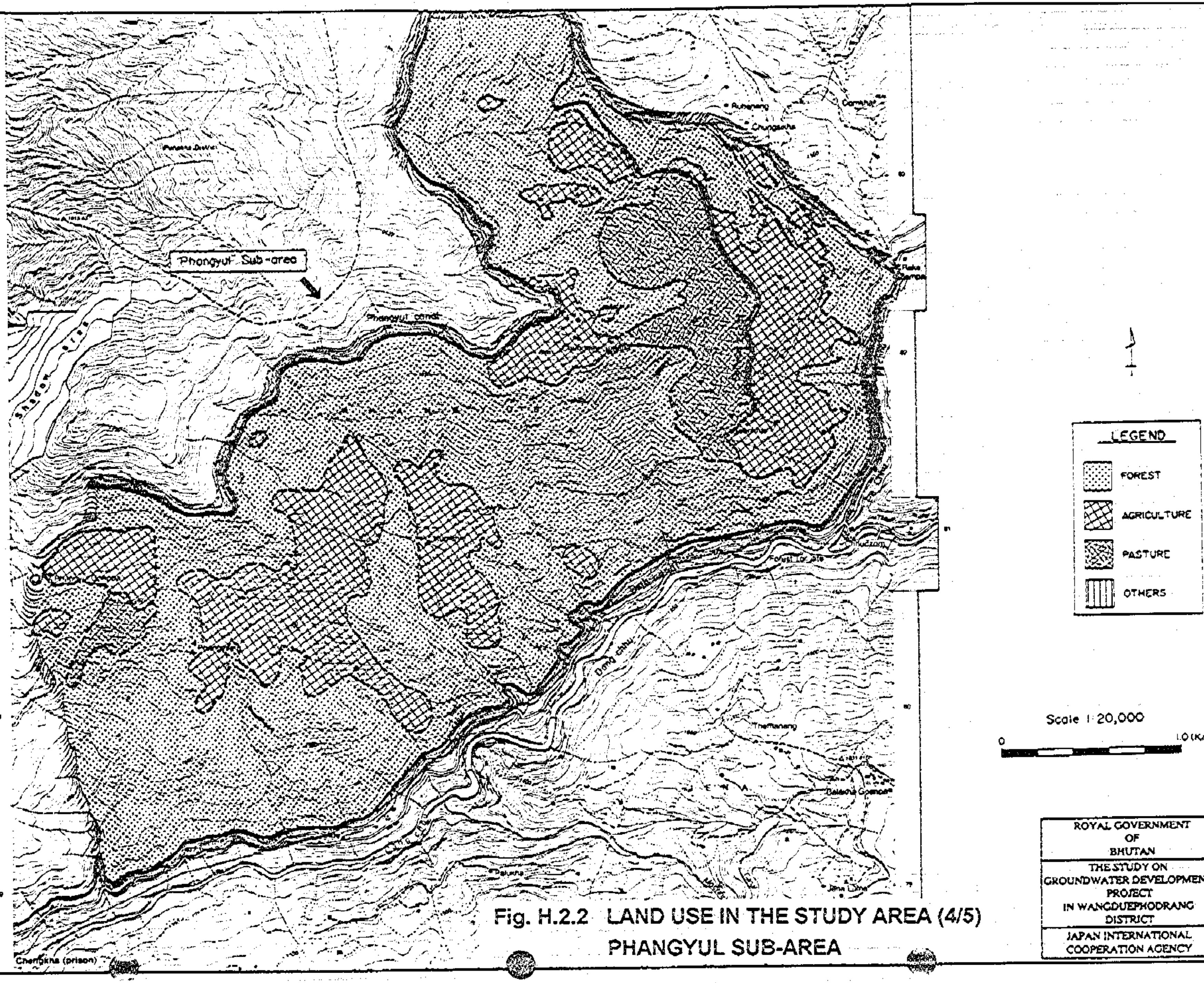


Fig. H.2.2 LAND USE IN THE STUDY AREA (4/5)
PHANGYUL SUB-AREA

ROYAL GOVERNMENT OF BHUTAN

THE STUDY ON GROUNDWATER DEVELOPMENT PROJECT IN WANGDUEPHODRANG DISTRICT

JAPAN INTERNATIONAL COOPERATION AGENCY

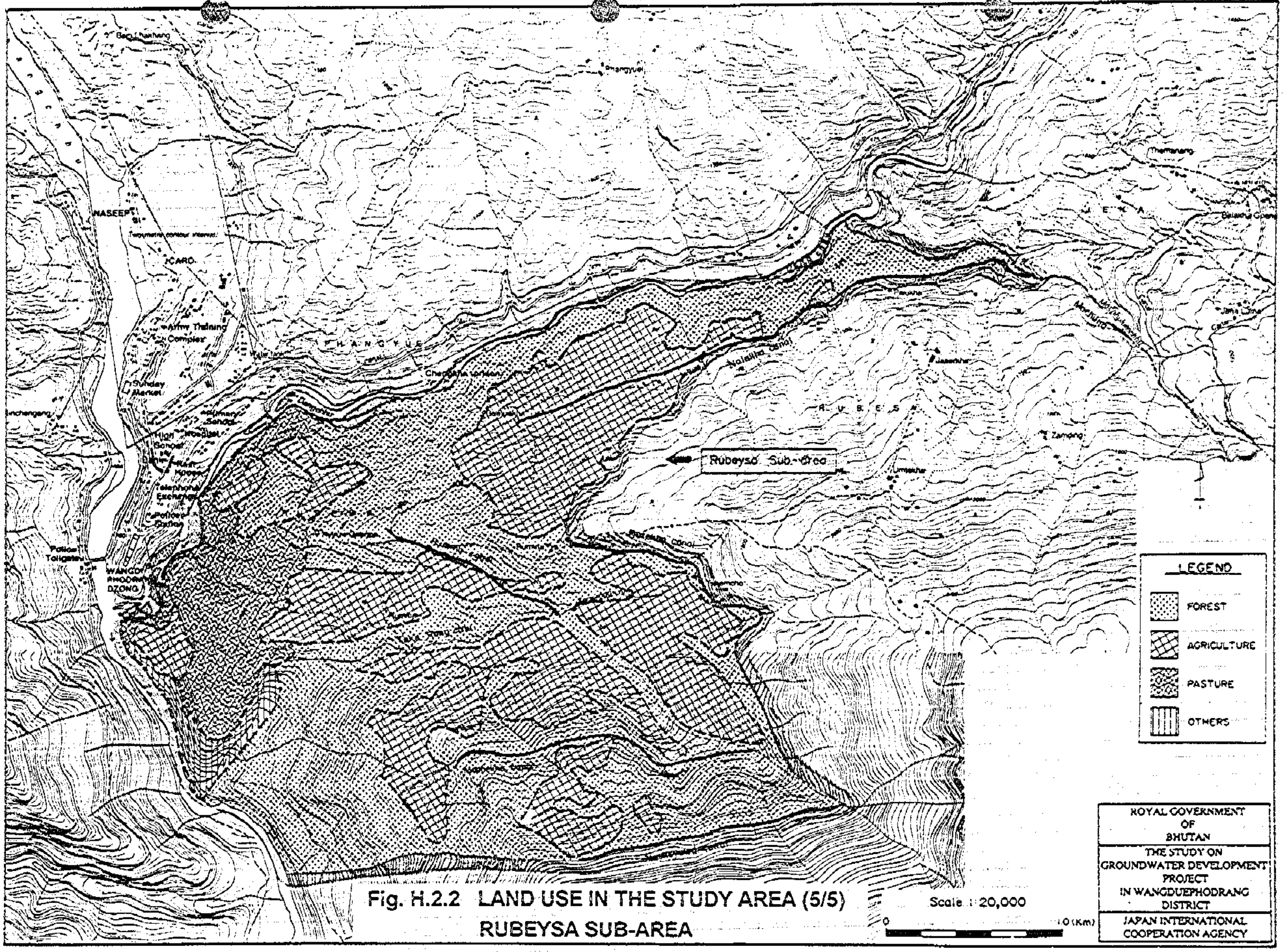
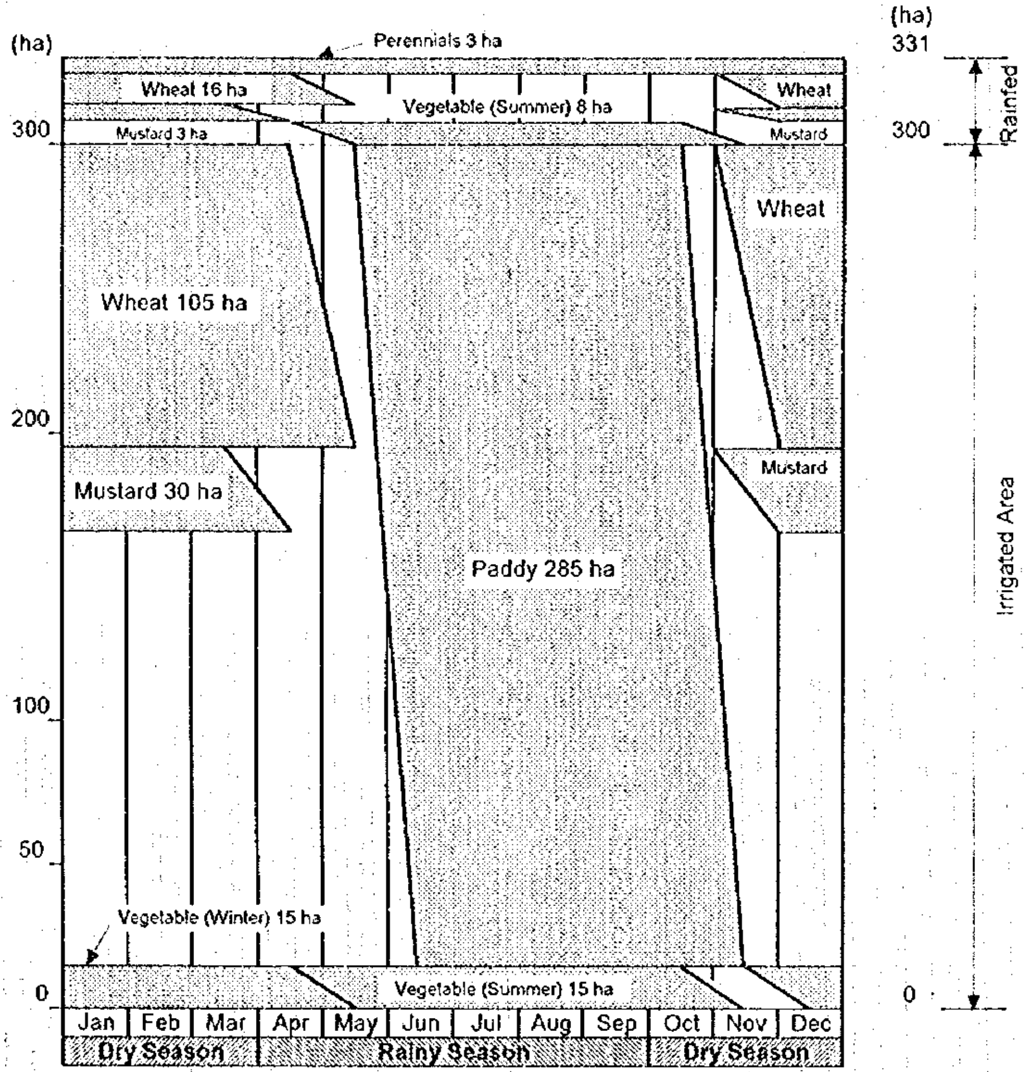
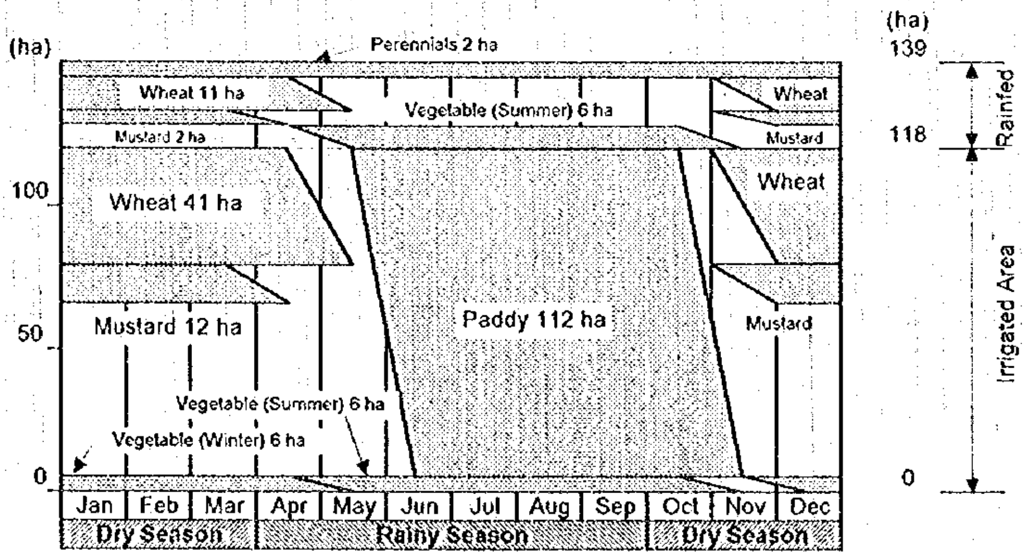


Fig. H.2.2 LAND USE IN THE STUDY AREA (5/5)
RUBEYSA SUB-AREA

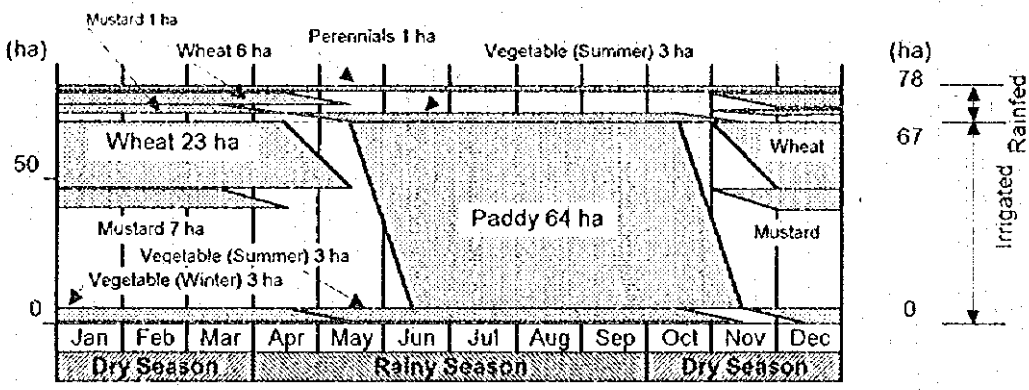


Lobeysa Sub-area

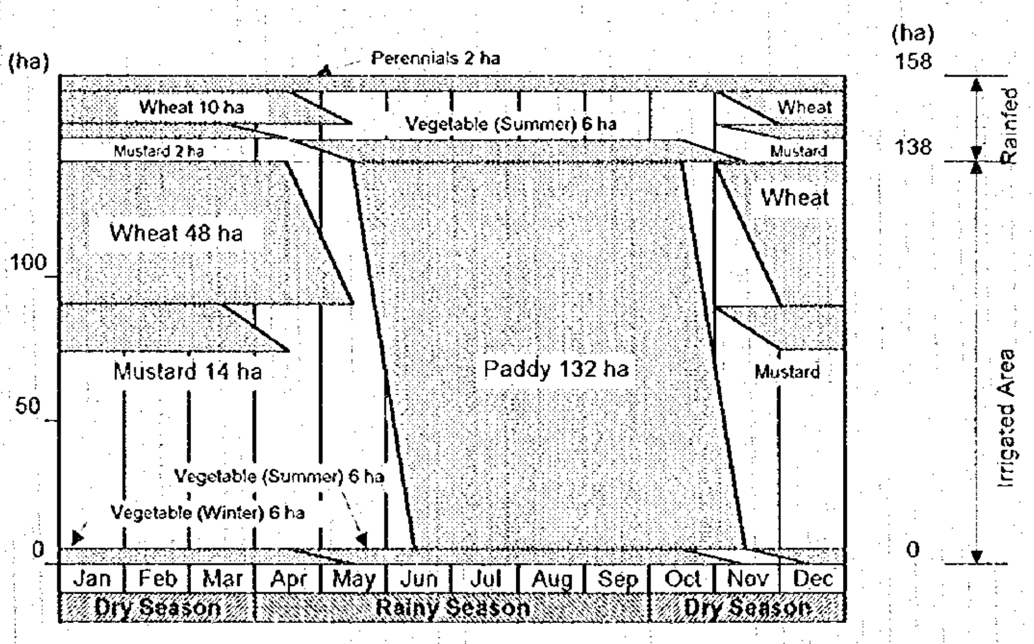


Bajo Sub-Area

Fig. H.2.3 Present Cropping Pattern in the Study Area (1/2)



Phangyul Sub-Area



Rubeysa Sub-Area

Fig. H.2.3 Present Cropping Pattern in the Study Area (2/2)

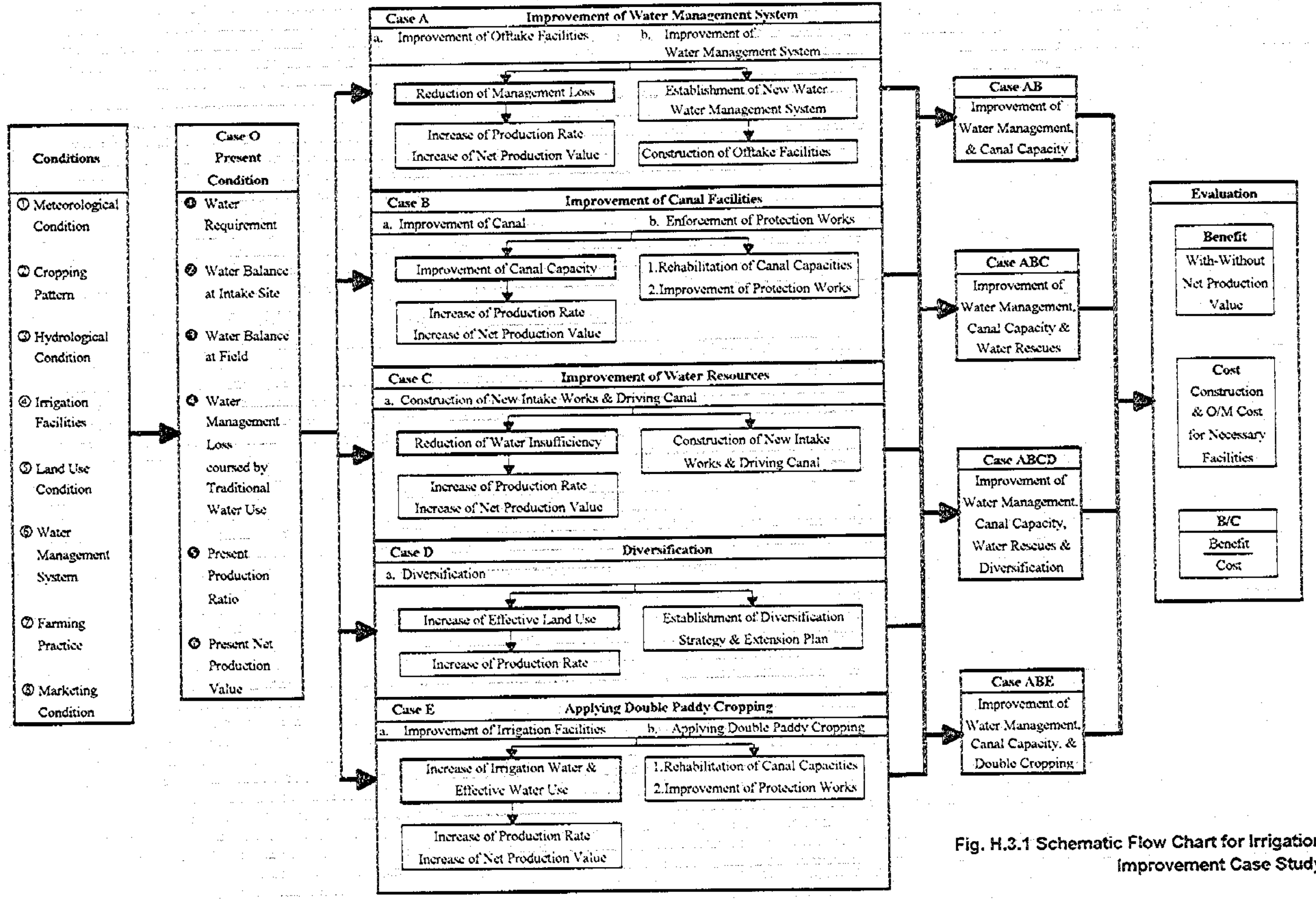
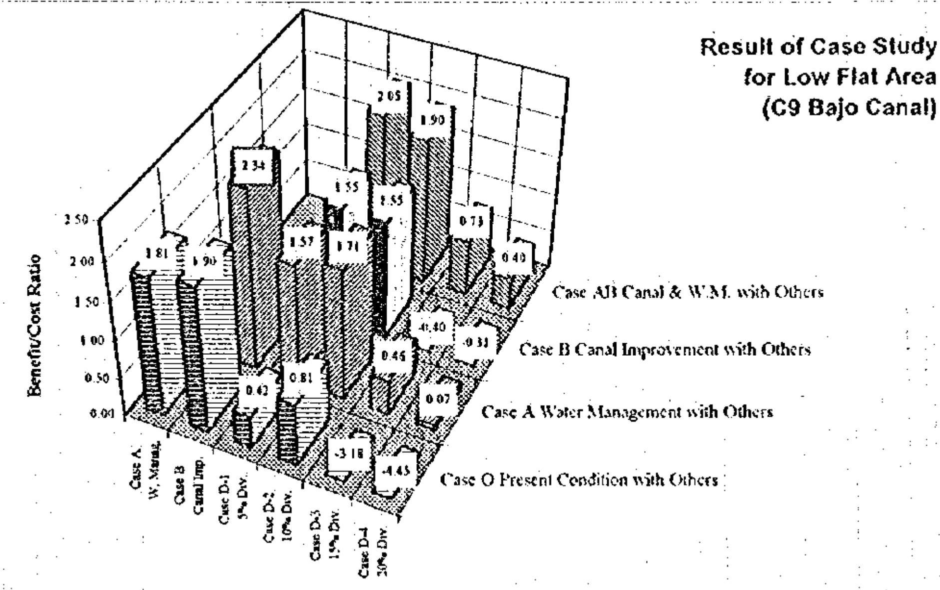
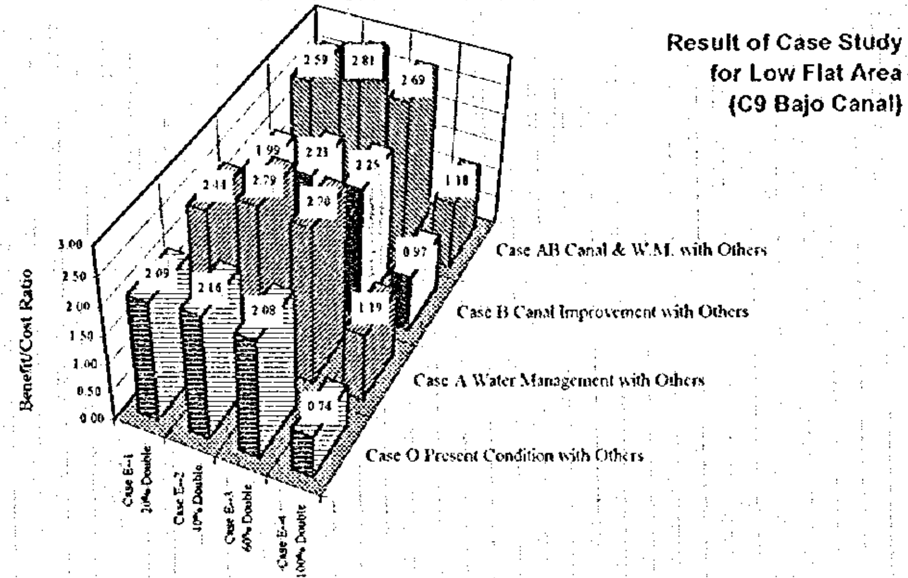


Fig. H.3.1 Schematic Flow Chart for Irrigation Improvement Case Study





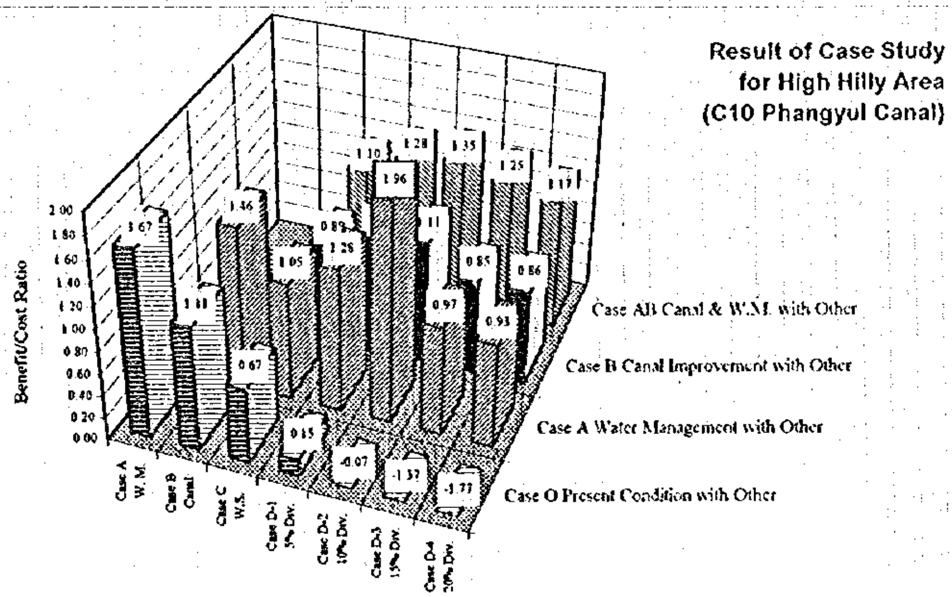
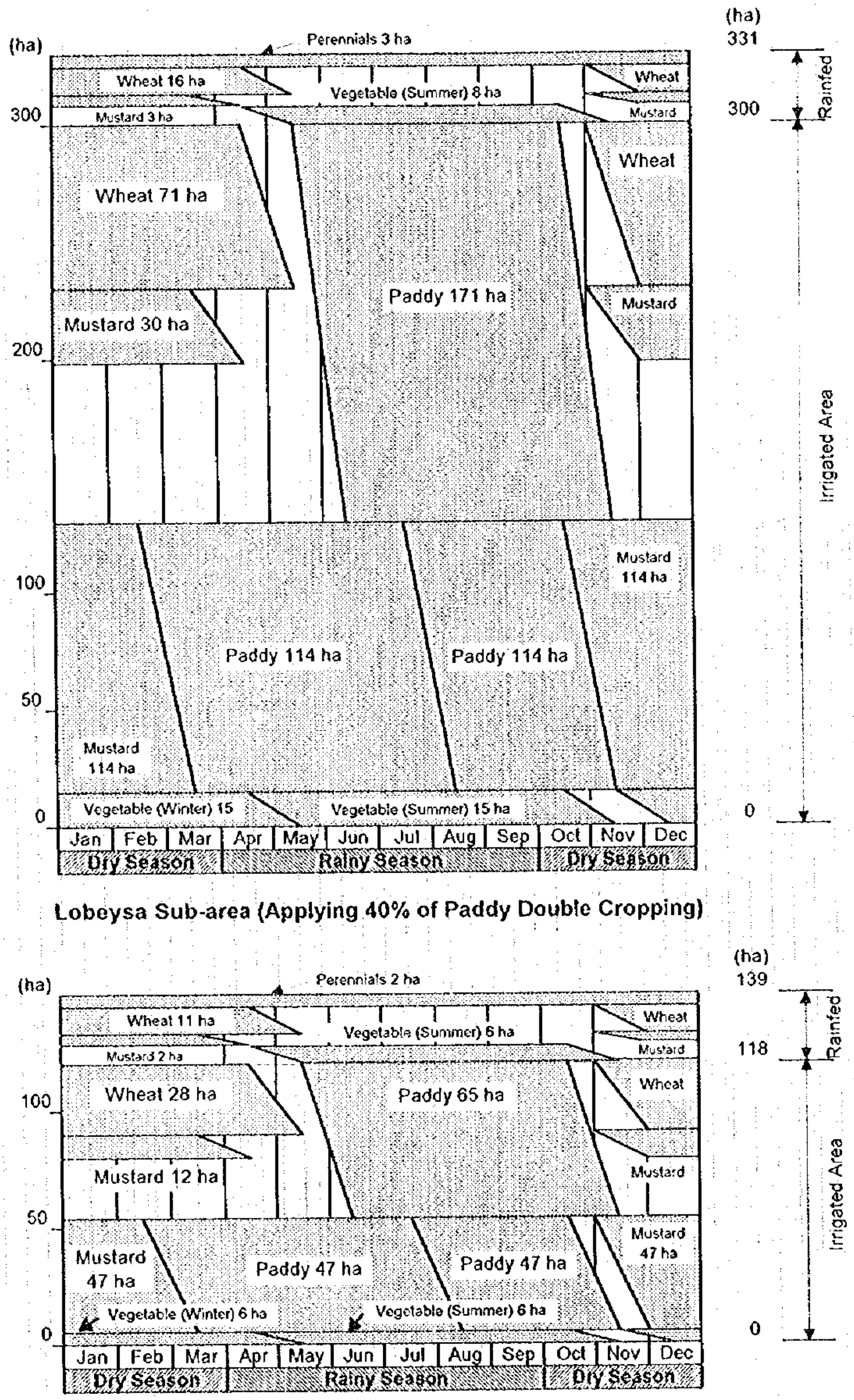


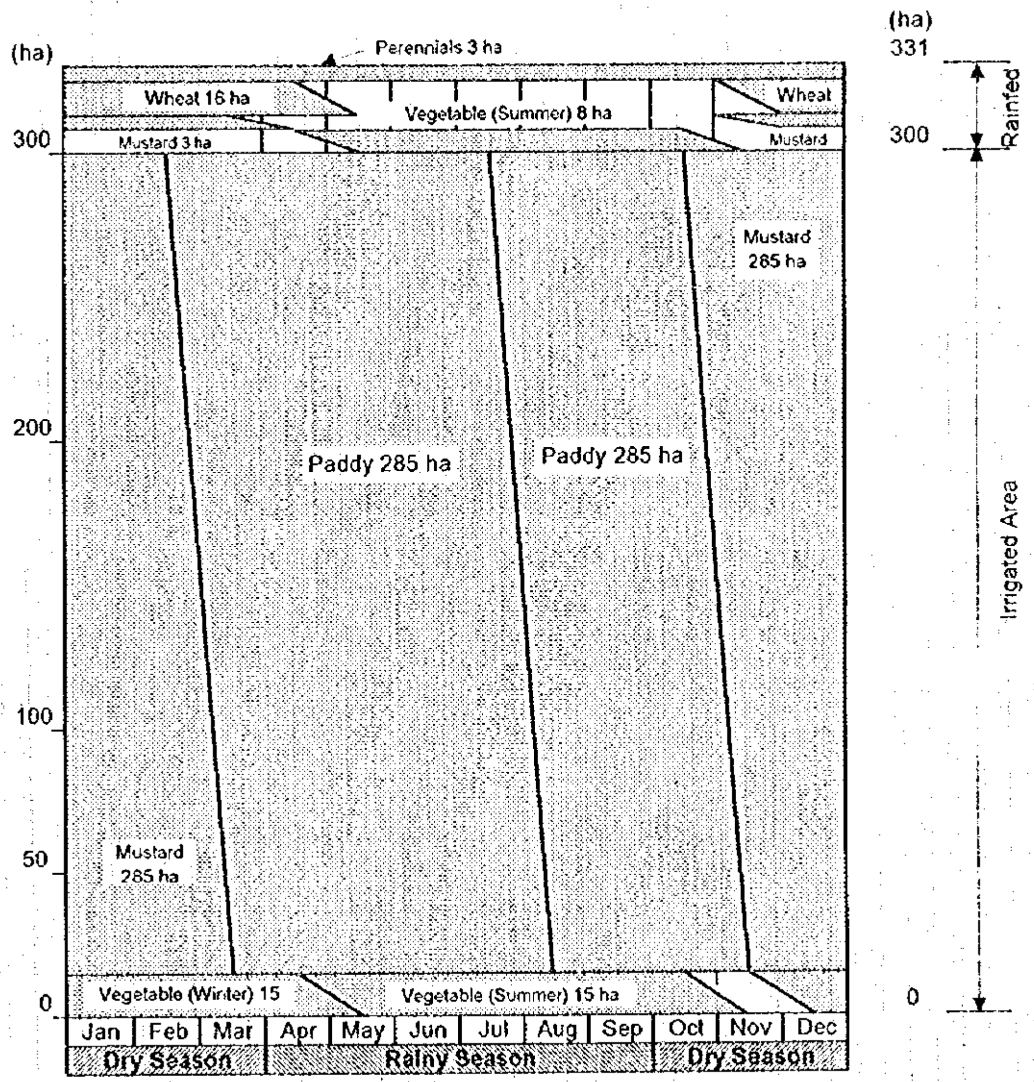
Fig. H.3.2 Result of Case Study



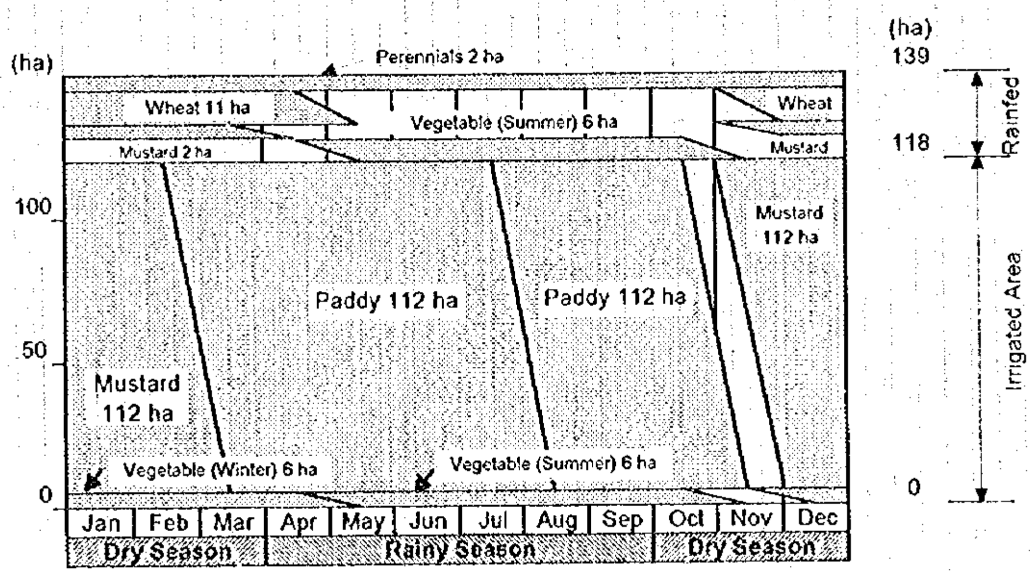
Lobeysa Sub-area (Applying 40% of Paddy Double Cropping)

Bajo Sub-Area (Applying 40% of Paddy Double Cropping)

Fig. H.4.1 Proposed Cropping Pattern (1/3)

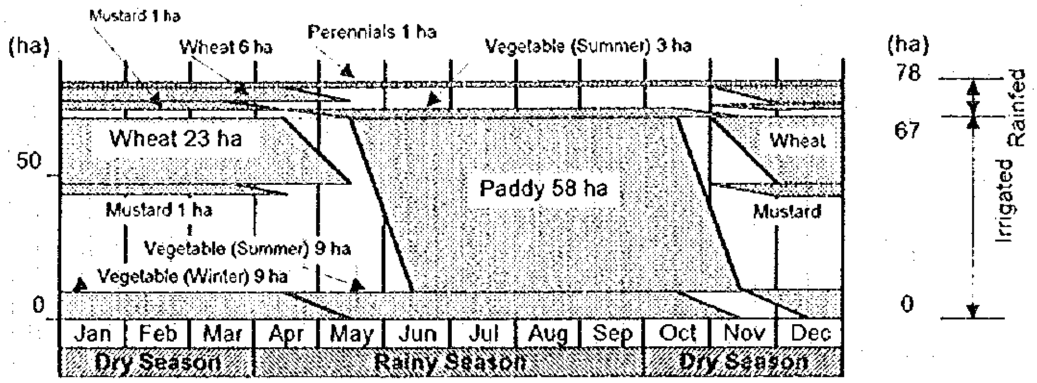


Lobeysa Sub-area (Applying 100% of Paddy Double Cropping)

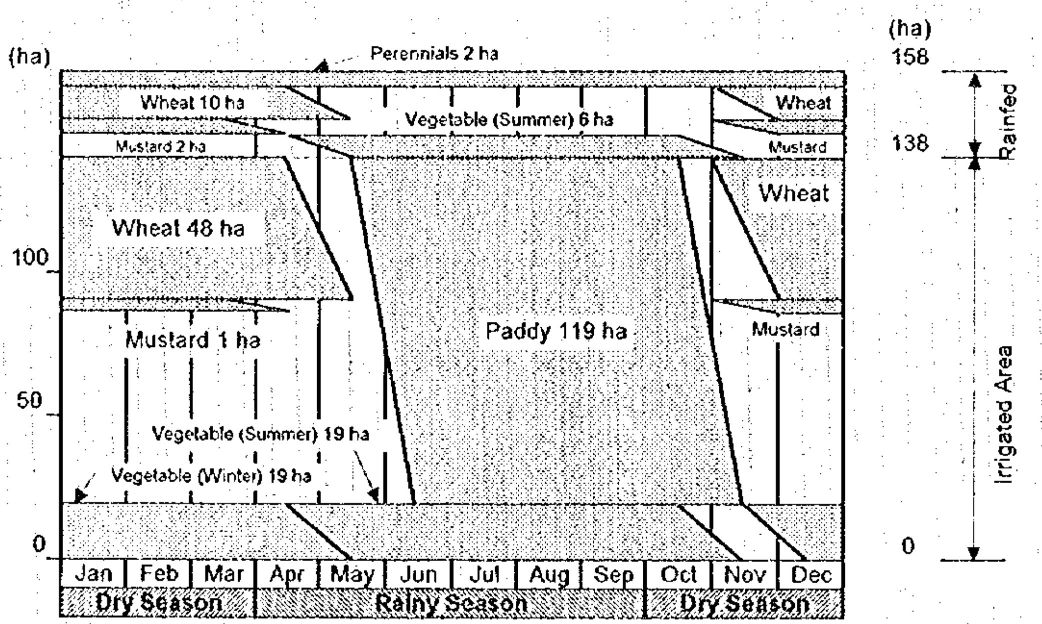


Bajo Sub-Area (Applying 100% of Paddy Double Cropping)

Fig. H.4.1 Proposed Cropping Pattern (2/3)



Phangyul Sub-Area (Applying 10% of Diversification)



Rubeysa Sub-Area (Applying 10% of Diversification)

Fig. H.4.1 Proposed Cropping Pattern (3/3)

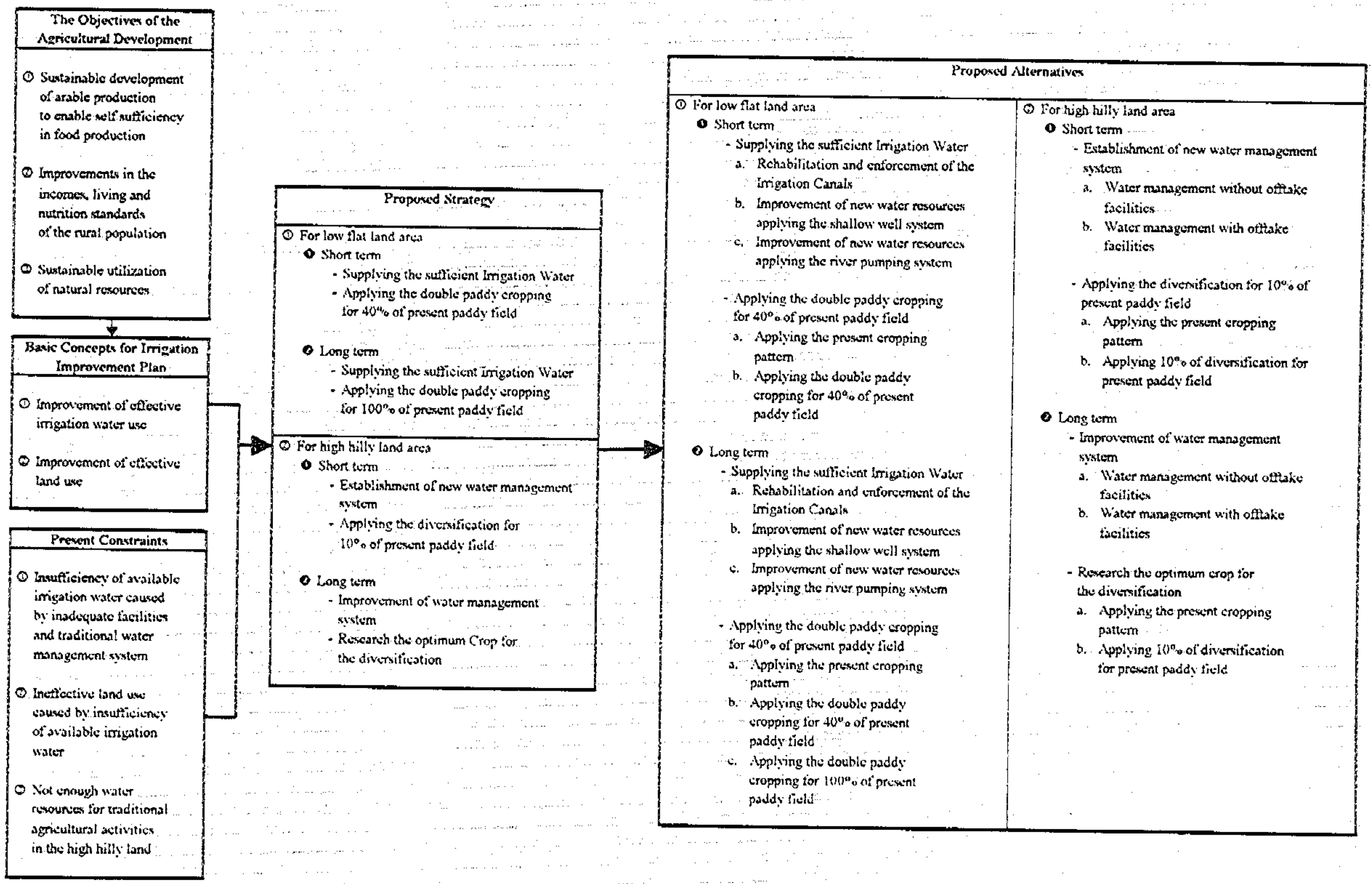


Fig. H.5.1 Schematic Flow of Alternatives

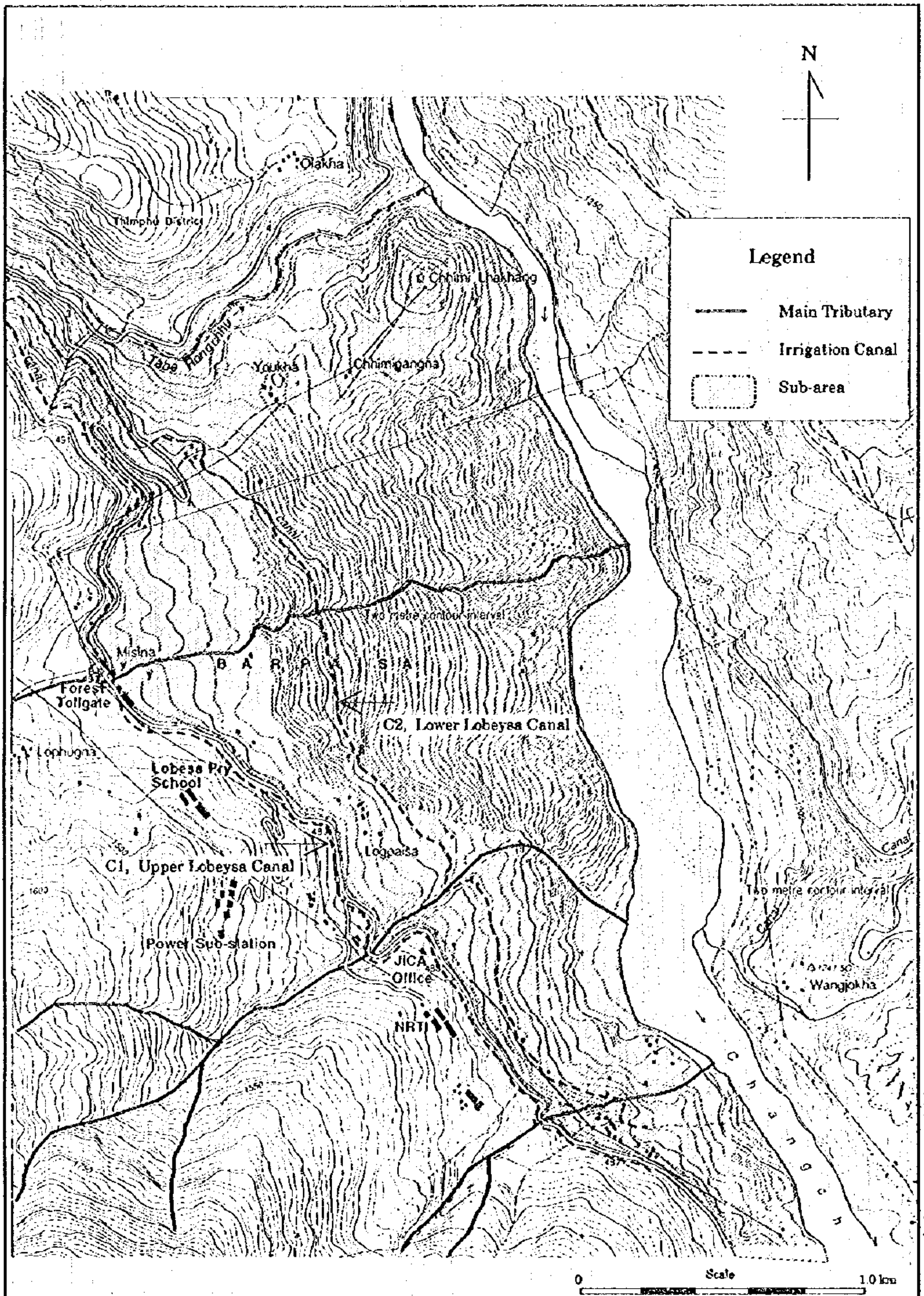


Fig. H.7.1 Main Drainage Tributaries in the Sub-Study Area (1/4)
(1) Lobeysa Sub-area

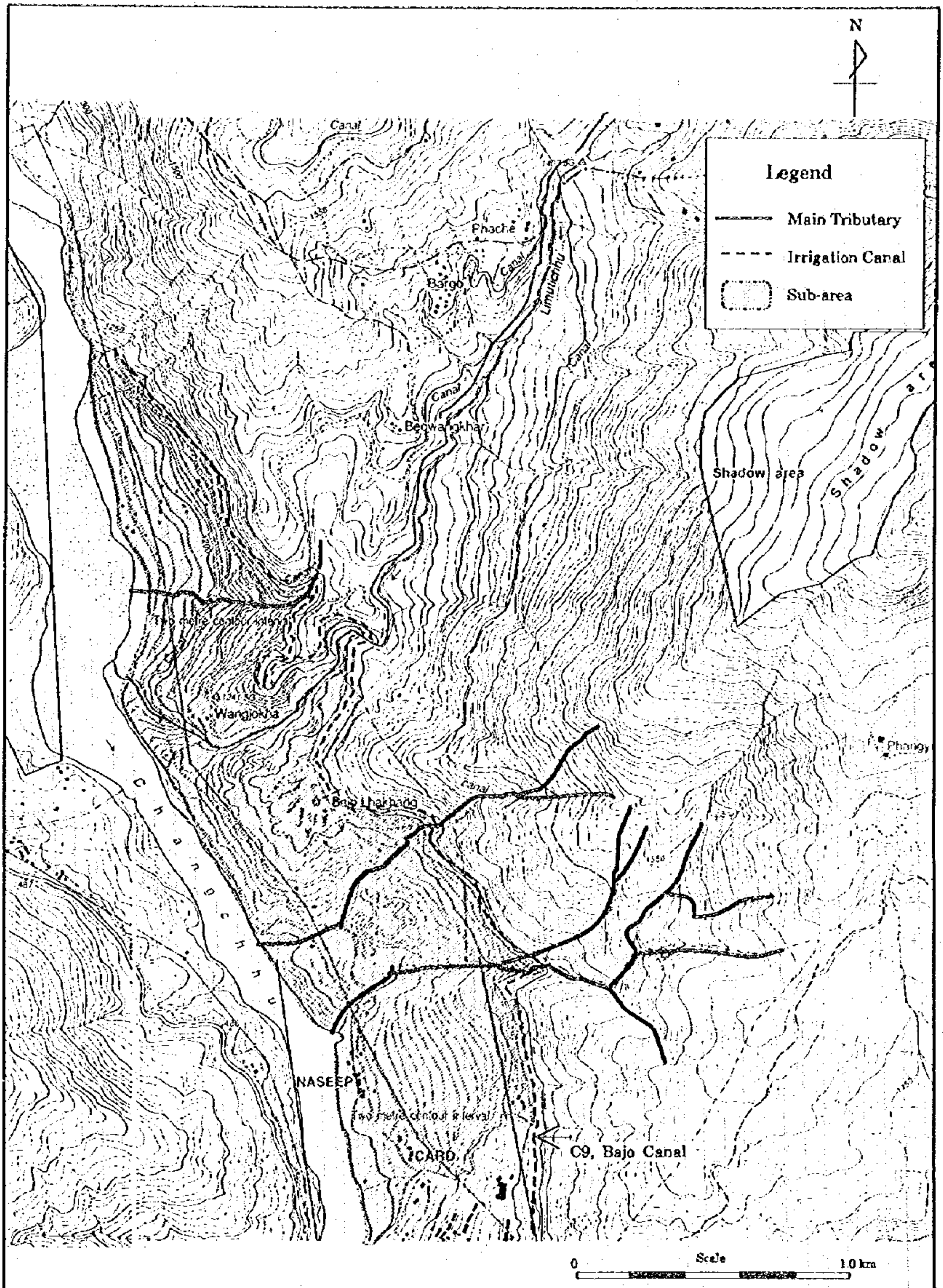


Fig. H.7.1 Main Drainage Tributaries in the Sub-Study Area (2/4)
(2) Bajo Sub-area

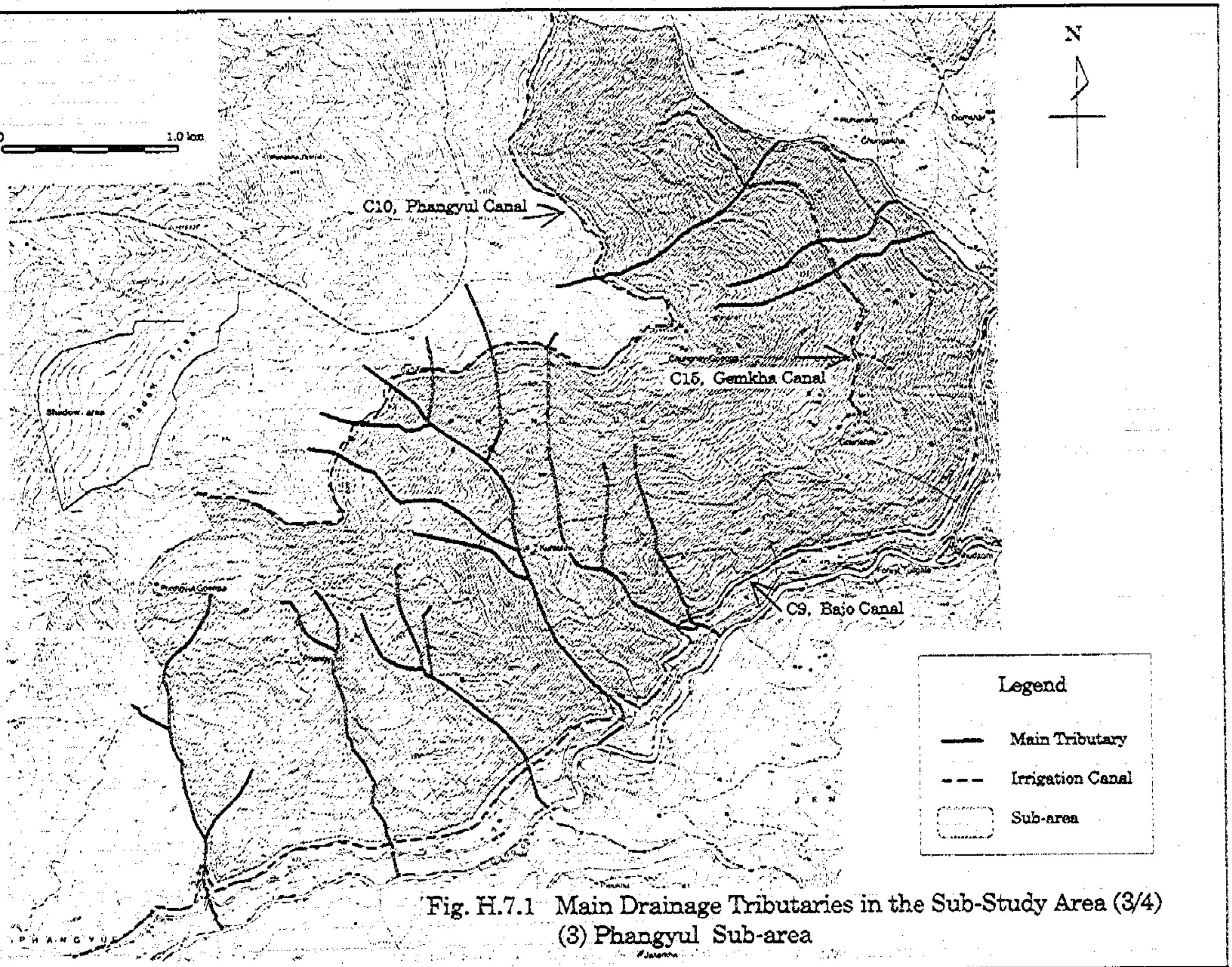


Fig. H.7.1 Main Drainage Tributaries in the Sub-Study Area (3/4)
(3) Phangyul Sub-area

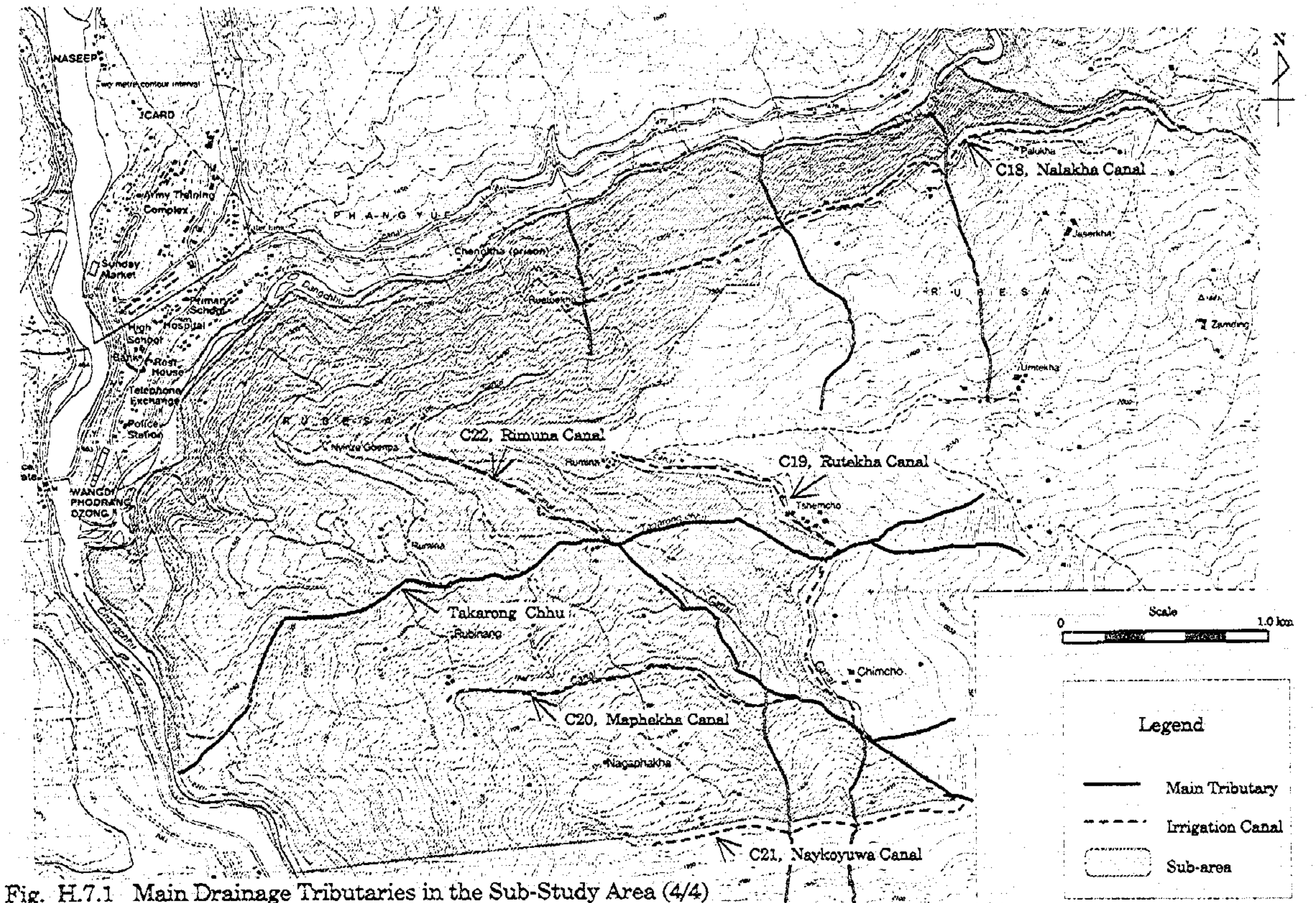


Fig. H.7.1 Main Drainage Tributaries in the Sub-Study Area (4/4)
(4) Rubeysa Sub-area

APPENDIX I
EXPERIMENTAL FACILITIES

THE STUDY
ON
GROUNDWATER DEVELOPMENT
IN
WANGDUEPHODRANG DISTRICT OF BHUTAN

FINAL REPORT

VOLUME III: SUPPORTING REPORT

APPENDIX-I IRRIGATION IMPROVEMENT STUDY

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APPENDIX-I EXPERIMENTAL FACILITIES

I.1 General

I.1.1 Objective and Concepts

In order to collect the data and information necessary for the establishment of the most appropriate plans for the water resources development projects, the experimental facilities were constructed during the Phase 2: Field Work.

These facilities were constructed to study on the appropriate development measures of water resources which include groundwater, spring water, subsurface water and river water. The most appropriate development measures of water resources have been studied and evaluated through the construction, operation/maintenance and monitoring of the experimental facilities. It is certain that the experience gained by this study will help to establish the adaptability and sustainability of water resources development systems as well as their use in Bhutan.

During the Phase 1: Field Work, a series of field reconnaissance surveys were carried out to examine the construction conditions and to observe the willingness of the government staff as well as the local people. Based on the results of the field reconnaissance survey, the proposed experimental facilities were selected among the various alternatives putting emphasis on the following considerations.

- Sustainability and adaptability of the facilities
- Smooth and painless introduction of the facilities as the works of the future projects
- Potential of proposed water sources
- Construction conditions of the proposed sites
- Necessary construction period

I.1.2 Proposed Scheme

Based on the considerations mentioned above, the following four (4) kinds of water resources exploitable in and around the Study Area were proposed;

- Groundwater scheme
- Spring water scheme
- Subsurface water scheme
- River water scheme

All of these resources are considered to be important and essential to mitigate the constraints of water utilization in the area. Therefore, it is proposed to select the facilities for each kind of water source, and it is necessary to consider the sustainability of these facilities.

The experimental facilities have been constructed in four (4) months period from November, 1994 to March 1995, by a local contractor under the supervision of the

Study Team. After the completion of their construction, the monitoring works were carried out to collect the necessary data and information for the Study.

The locations of the facilities are presented in Fig. I.1.1.

I.1.3 Monitoring Works

After completion of the construction of experimental facilities, the monitoring works were commenced in order to evaluate the performance, applicability, technical feasibility etc. of such facilities. The monitoring works were continued till the end of August 1995, which is the end of field survey of the Study Team.

The purpose and the items of monitoring of each facility are summarized in Fig. I.1.2 and required staff for the monitoring were considered as described below;

(1) Formation of Monitoring Works

The monitoring works consist of operation and observation works. The operation work is to operate and maintain the installed equipment of experimental facilities in a favorable condition, and the observation work is to conduct the observation collecting and recording necessary data of the experimental facilities.

The observation works to be made in this monitoring, is further divided into the following items:

- daily routine observation to be conducted whenever the facilities are operated,
- periodical observation to be conducted with some frequency of one (1) week, 10 days or one (1)month period, and
- collection of data and information necessary for the monitoring such as meteorological and hydrological records, etc.

Since the solar powered pumping facility (ground water scheme) and the slide type pumping station (river water scheme) are located in the farm yard of RNR-RC in Bajo, the operation of such facility was conducted by the staff of the RNR-RC in Bajo. The routine and periodical observation works were also conducted by RNR-RC in Bajo and those works were inspected by qualified engineers and technicians during the operation period in order to ensure the proper operation.

As for the spring water storage facility (spring water scheme) in the Phangyul area and the shallow well pumping facility (subsurface water scheme) in the Bajo area, it was considered that operating the facility and monitoring their performance shall be carried out with a certain amount of skill. The routine monitoring works of these facilities were conducted by local people who utilize these facilities.

The meteorological records required for monitoring were collected by the counterpart staff in RNR-RC office, and were compiled by them. In order to ensure the observation works of the experimental facilities, the observation works were carried out by RNR-RC staff and local people at each site of experimental facility under the management and control of the project's counterpart staff. The observation data was recorded in the monitoring record books of each experimental facility.

The formation of the above monitoring system is illustrated in Fig. I.1.3.

(2) Required Staff

Three (3) counterpart staff of the project were assigned and they were in charge of overall controlling and managing of monitoring works to be conducted by the RNR-RC staff and local people. Technology transfer to the counterpart staff was carried out through on-the-job training in the course of the construction and monitoring of the experimental facilities.

The required number of the staff and local people to be assigned for executing monitoring works of each experimental facility is tabulated below.

Experimental Facility	RNR-RC staff	Local People
Solar Powered Pumping Facility	1	-
Spring Water Storage Facility	-	1
Shallow Well Pumping Facility	-	1
River Pumping Station	2	-
Total	3	2

I.2 Groundwater Scheme : Water Supply Facility of Deep Well in the RNR-RC in Bajo

I.2.1 Summary of Facility Plan

(1) Basic Conditions

The deep well water supply facility was constructed utilizing the test well drilled in RNR-RC in Bajo in Phase 1: Field Work.

A solar powered pumping system is employed for lifting up the groundwater. Although the initial investment cost for the solar power pumping unit is considered to be a bit expensive, the operation and maintenance cost is expected to be cheaper comparing with the other type of systems. In Bhutan, the solar power system has been applied for the telecommunication networks so far, and is functioning well. Therefore, this solar power system is considered to be one of the recommendable measures to attain sustainable development in the water resources development sector.

From the result of the meteo-hydrological study, 5.4 hr/day of average sunshine hour can be expected in the Wangdue Valley. A large amount of electric power cannot be expected from the solar system, and therefore, this system may not be applied for the large scale facilities such as irrigation pumping system. Since the output power can be controlled adequately using the VVVF type inverter, it is possible to apply the solar system for the small scale facilities such as a small scale water supply system.

In order to examine and confirm the performance, technical feasibility, and adaptability of solar power system, the solar power system was proposed as one of the alternative power sources in this system.

(2) Proposed Component of the System

A solar powered pumping system was applied for lifting up the groundwater, and a water supply system consisting of an elevated water tank and pipeline networks was provided for distributing domestic water to the offices and the staff quarters in the RNR-RC in Bajo. To ensure the daily operation of pumping facilities against the shortage of solar power in cloudy or rainy days, the system is connected to the public electric power supply networks. The schematic diagram of the system is presented in Fig. I.2.1.

(3) Design Conditions

The following conditions were considered in designing the Water Supply Facility of Deep Well in the RNR-RC in Bajo.

1) Population Served

Groundwater is served for about 50 persons, which include 30 staff of RNR-RC office who consume the water during the day time and 20 inhabitants of residential quarters who consume the water during day and night time.

2) Design Water Demand

A design daily water demand of 160 l/person/day was applied for determining the capacity of facility considering the results of the domestic water demand study executed in the Phase 1 study.

3) Design Capacity of Elevated Water Tank

Design capacity of the elevated water tank is set at 4.0 m^3 considering that the groundwater would be lifted up twice a day based on the daily water demand of 160 l/person and the served population of 50.

4) Design Conditions of Solar System

The design conditions of the solar system in the groundwater scheme are summarized as shown below;

- Average sunshine duration : 5.4 hr/day (roughly as estimated 4.3 hr•Kw/m^2/day)
- Total Head : 50 m
- Pumping Capacity : 8 m^3/day
- Casing pipe diameter : 4 inches
- Dynamic water level for well : -35 m from ground level

- Type of pump : Multi-stage centrifugal submersible pump with VVVF type inverter
- Electrical Specifications
  - Voltage : 3 x 65V
  - Power : 550W, 0.75 HP
  - Current : 8.8 A
  - Power rate : 0.87
  - Maximum output : 1,200 W

Using the mean annual radiation of sunshine and Fig. I.2.2, the capacity of solar battery was estimated as approx. 1,113 Wp (880 Wp for effective capacity). By applying the solar panels with a power of 53 Wp/unit, 21 units of solar panel are required. According to Fig I.2.2, approx. 10 m^3/day of water discharge was expected.

(4) Principal Features of the Facility

The general plan and layout plan of the proposed facility are shown in Fig I.2.3~5. The principal features of the constructed facilities are summarized below;

1) Deep Well Pumping Unit

a) Submersible motor pump
- Type of pump : Multi-stage centrifugal submersible pump
- Casing pipe diameter : 4 inches
- Total head : 50 m (Dynamic water level GL-35 m)
- Pumping capacity : 8 m^3/day

b) Electrical specifications
- Voltage : 3 x 65V
- Power : 550W, 0.75HP.
- Current : 8.8A

c) Control panel

The control panel is provided with a control facility to shift the operation from solar power to electric power supply and vice versa.

- Solar power driven :
  The inverter converts the DC power from the solar array into three phases of AC power which is transmitted to the submersible motor. The AC output voltage and frequency vary continuously as a function of the irradiation. The system utilizes the power output of the solar DC generating system to an absolute maximum by means of maximum power point tracking.

- Electric power driven :
  The control panel is provided with a transformer which can convert the voltage from 440V to 65V.

d) Solar array

The highly efficient solar modules are connected in series and in parallel to form a complete solar array with a nominal output voltage of approx. 65V DC. The output current varies with the irradiation on the array. The DC output from the array is transmitted to the inverter through a main switch in the inverter.

2) Existing Electric Power Supply

- Power source : 440 V, 50 Hz, 3 Phases
- Additional power line : Approx. 60 m with 2 electric poles

3) Elevated Water Tank

a) Storage tank
- Capacity : 4 m^3
- Dimensions : 2 (L) X 2 (B) X 1(H) m
- Material : SMC panel tank

b) Tower
- Height : 6 m
- Material : Steel structure

c) Distribution Pipes
- Material : Galvanized steel pipe
- Lengths and diameters : 390 m (2 in. dia.)
  : 230 m (1 in. dia.)

d) Ancillary Facilities
- Public water storage tank : 1 unit (500 l.)
- Public water tap : 1 unit

I.2.2 Monitoring Works for the Ground Water Scheme

(1) Purpose of Monitoring

The solar powered pumping systems can be used in remote areas where the sunshine is plentiful and no electric power supply is available. Though this power system has already proved to be successful for the technical applications in the country for the lighting facilities and the telecommunication networks, the technical feasibility, the performance and the applicability of the facility to water supply projects were examined through the trials.

(2) Results of Monitoring Works

The monitoring work was carried out from the end of April to the end of August 1995. The following data were collected/monitored during the monitoring period.

- Daily sunshine hours
- Pumped up water volume by solar power and electric power supply
- Relation of frequency and discharge by solar power driven pump

1) Daily Sunshine Hours

The data on the daily sunshine hours were collected from the meteorological station at RNR-RC in Bajo. The monthly average of sunshine duration (hr/day) at the station is summarized as shown below.

Duration of Sunshine 1990~1995

unit : hr/day

Jan	Feb	Mar.	Apr.	May	June	July	Aug	Sep.	Oct.	Nov.	Dec.
4.9	5.3	5.8	5.7	4.8	4.8	4.8	5.0	6.5	6.5	6.6	6.1

The mean annual duration of sunshine was estimated as 5.4hr/day. The mean monthly duration of sunshine is generally higher during the period from October to December than from May to August. The daily sunshine data during the monitoring period is shown in Table I.2.1.

2) Pumped Up Water Volume by Solar Power and Electric Power Supply

a) Pumped Up Water Volume by Solar Power and Electric Power Supply

In order to observe and estimate the solar power system, the routine observation works of each pumping operation were conducted by the staff of the RNR-RC in Bajo and the selection of switching over between solar power and electric power was done manually in accordance with the weather conditions. In addition to the pumping operation record, the accumulative flow were recorded using flow meter on the distribution pipe at the pumping station. While using the solar power, the blow off valve of the storage tank was opened continuously considering the variation of solar power. The pumping operation record is shown in the Data Book IV.

Using the accumulative flow data, the amount of daily pumping up water was calculated as shown in Table I.2.1 and Fig.I.2.6. The result is summarized below ;

Summary of Estimated Pumping Discharge (m^3/day)

	May	June	July	August
Solar	8.7	3.5	4.7	6.0
Public	0.3	0.7	0.9	0.8
Total	8.9	4.2	5.6	6.8
(Sunshine hr/day)	(6.8)	(2.8)	(3.8)	(5.1)

As mentioned above, when the solar system was functioning, the water tap of the pipeline was not controlled for the purpose of inspecting the capacity of the solar system. Therefore, the amount of water discharge does not show the actual conditions of water consumption.

b) Relation of Frequency and Discharge in the Weather Conditions

Since the main source of power for the facilities is solar power, design sunshine hour of the facilities shall be decided based on the sunshine duration and condition.

Pumping of ground water was carried out in proportion to sunshine duration. However, public power was also utilized in spite that the sunshine occurred for a duration of more than about 5 hours on 11th of July and 11th of August, mainly due to the conditions of sunshine.
Amount of sunshine irradiation was monitored as output from solar panel between fine and cloudy conditions using frequency measurement and cumulative flow meter. Result of the output is shown in Fig.I.2.8. Since the output required for driving the solar pump, is more than 50 Hz frequency, the intermediate sunshine irradiation is not enough to drive the pump.
Accordingly, when solar radiation is available continuously, solar power can be used as the power source. And power storage equipment must be necessary for the solar power system.
Based on the monitoring data observed during the field survey, the available sunshine time period is estimated from 10:00 to 15:00 in the topographic conditions of Wangduephodrang.

I.2.3 Evaluation and Recommendation

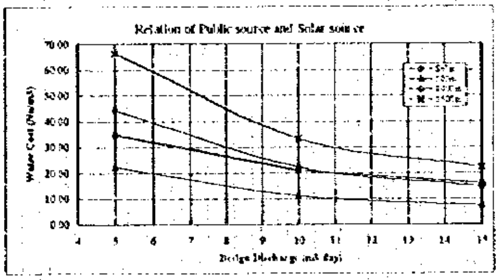
(1) Evaluation of System

In Bhutan, this study is the first case of applying the solar powered pumping system for the water supply and the monitoring was carried out only for 5 months period. Based on monitoring data, the solar system was evaluated as described below;

The solar power depends on the weather conditions, and specification of the solar system and its efficiency is proportional to the sunshine radiation volume and time duration of the solar radiation. As a result of the monitoring it was found out that the solar powered system pumped up a water volume of 5.7 m^3/day in rainy season, and the water volume per unit of sunshine hour is estimated roughly asbabout 1.2 m^3. Amount of water is estimated to increase in dry season by applying the solar system. It is technically possible to apply the solar system for domestic water supply even in the weather conditions of rainy season. In Wangduephodrang, it is possible to apply water demand of more or less 5.7 m^3/day based on the monitoring data. Besides, manual switching operation will be difficult in proportion to weather conditions since weather conditions are not stabilized in rainy season, and therefore application equipment for storage is necessary.

The storage equipment is classified into two types ; One is the battery for electricity and the other is tank for storing water. The battery system is confirmed to have some problems such as irregular operation, life of the battery and high cost. Since construction and maintenance of the tank are easy in Bhutan, the storage tank shall be employed to store the water in place of the battery. Besides, it is necessary to educate the local people to control the water tap for saving the pumping up water.

The result of alternative study based on the initial O/M cost is shown below. It is expected that applying the solar power system will be more effective than using the public power line for pumping up water depending on the site conditions. However, in case of applying the solar power system for domestic water use in Bhutan, there is also a fear that the system may be down for a long term when there will be a break down in the system due to unexpected accidents, since importing the spare parts will take considerable amount of time. Consequently, further detailed investigation should be required for applying the solar power, and training for the operation and maintenance of the system is necessary.



(2) Recommendation of the Future Plan

The solar power was introduced into Bhutan since 1980's for small lighting purposes in a number of the public facilities, which is school, hospital as well as some private households. These solar facilities were almost successful and further installations are undertaken and under planning for lighting purposes in remote areas. However, comparing with lighting and domestic water, if lighting system is failed by an unexpected accident, it is possible to utilize another equipment, but the domestic water system can not be operated using other equipment. Besides, since the spare parts of the solar system should be imported from other country, there is a problem that the functioning of the facility may have to be stopped for a few months period.

Since the topographic conditions of Bhutan has many mountainous area, the solar system will be affected by the shadow by mountain and fog, etc.. Therefore, it is considered to apply only solar power system for pumping facilities with some constraints mentioned above. Besides, in order to prevent from such unexpected accidents, a supplemental power line is necessary for applying the solar power system for domestic water supply.

Based on the above mentioned items, the following recommendations are made for adapting the solar power system :

1) Selection of design sunshine hour and Location of Solar Panel

As the result of the monitoring work, as mentioned in the section on '2) Pumped Up Water Volume by Solar Power and Electric Power Supply', the discharge is variable in proportion to sunshine conditions, which is the amount of sunshine and sunshine hour and the utilization of the solar powered facilities is restricted to design sunshine hour. Since sunshine hour is decided by the topographic conditions, such as the sunshine irradiation angle, latitude and longitude of the project site and topographic conditions in the project site is variable in landuse and water utilization, location of solar panel must be considered to utilize the maximum sunshine hour.

The design sunshine hour is decided to suit for the facilities based on average sunshine hour in observed years and considering available coefficient. Besides, recording of the sunshine data must be added to the rainfall data and sunshine time zone.

2) Capacity of the storage tank

Necessity of the storage tank is concluded from the results of the study, and the capacity of the storage tank is decided considering the water demand, time zone and daily sunshine duration. It is important to provide sufficient storage to cover periods of the night time and bad weather conditions, when the output from the solar pump will be low or stopped.

It is recommended that the capacity of the tank shall be designed to supply the planned maximum daily supply water in 8~12 hours.

I.3 Spring Water Scheme : Spring Water Storage Facility in Phangyul Area

I.3.1 Summary of Facility Plan

(1) General Condition

The reliable water source is quite scarce in the Phangyul area. Although most of the mountain spring in the Phangyul area is utilized to the maximum extent, villagers still have to face water shortage troubles in both of rural and irrigation water supply.

In this area it is believed to be important to utilize the spring water as effectively as possible. In the spring of the proper Phangyul, the spring water is collected and conveyed to the village with a polyethylene pipe, and the unused spring water is left wasted as it flows because no water tap is fitted at the outlet.

To utilize such unused wasted water effectively, installation of water tap was proposed at the outlet of the pipe. The construction of storage tank was also proposed near the spring to store such wasted water as much as possible. The water stored in the storage tank was conveyed to the existing canal for supplementary irrigation of rice cultivation in the rainy season. According to the rough calculation made in the preliminary study, the available water supply is expected to increase by 5 to 15% by applying water tap and storage tank.

(2) Proposed Component of the System

As schematically presented in Fig. I.3.1, the system was proposed to be composed of water tap at the outlet of polyethylene pipe, storage water tank, and collecting ditch. When the water tap is closed, the spring water will be spilled out from the spring basin, and flows down to the collecting ditch through the wet swamp area. The collected water is stored in the water storage tank.

(3) Design Conditions

The following conditions were considered in designing Spring Water Storage Facility in Phangyul Area.

1) Water Tap

An ordinary type of water tap was fitted at the outlet of the polyethylene pipe from the spring basin.

2) Collecting Ditch

A collecting ditch of dry masonry to collect spilled water from the spring basin is dug so as to pass the wet swamp area located in front of the spring basin. The collected water is conveyed to the water storage tank through the conveyance canal of wet masonry.

3) Storage Tank

A storage tank was constructed at the corner of flat area. The storage tank is used to store water as well as to measure the volume of water which is spilled out from the spring basin. Based on the topographic condition, the design capacity of the tank was set at 70 m^3 and it was expected that the tank would be filled every 7 to 10 days considering expected spring discharge of 4 - 8 l/min during the dry season.

The SMC panel was proposed for the storage tank to facilitate the construction in the limited study period.

(4) Principal Features of Facility

The principal features of the constructed facilities are summarized below, and the general plan and layout plan of the proposed facility are shown in Fig. I.3.2.

1) Intake facility

- Spring water collecting pit : Stone masonry
- Collecting ditch : Length 35 m, Height 0.4 m, Bottom width 0.4 m

2) Water Conveyance Canal

- Earthen ditch : Length 15 m, Height 0.4 m, Bottom width 0.4 m

- Stone masonry canal : Length 25 m, Height 0.4 m, Bottom width 0.4 m
- Desanding pit : 1 unit

3) Storage tank

- Capacity : 70 m^3
- Dimensions : 6(L) x 6(B) x 2 (H) m
- Material : SMC panel tank

4) Related Structure

- Wash basin : 4 m^2 (concrete)
- Delivery pipe : 3 inches, 20 m, PVC

I.3.2 Monitoring Works for Spring Water Scheme

(1) Purpose of Monitoring

A water tap was installed at the outlet of the pipeline from the spring basin to reduce the waste of spring water. A water storage tank was constructed to store such spring water which spills out from the spring basin due to installation of the water tap. The main purpose of monitoring is to measure volume of the spring water which spills out from the spring basin. From the view point of water use, the effect of storage tank should be also clarified through the monitoring operation.

(2) Monitoring Works

The monitoring works was carried out from the beginning of May to the end of August, 1995 except for a few weeks in May and June during the repairing works for the leakage of storage tank.

The following items were monitored to measure the effects by installing a water tap at the outlet of pipeline.

- Volume of Spring Water Saved by Installing Water Tap
- Use of the Saved Water

1) Estimation Spring Discharge Saved by Installing Water Tap

The daily water level in the water storage tank was observed by the village people periodically every day as shown in the Data Book IV. The spring water discharge is estimated from measuring water level of the storage tank by the counterpart staff once a week periodically. The water level of the storage tank was measured by setting a transparent vinyl hose vertically on the tank wall and by fixing a steel gauge plate beside the hose on the wall. The water level in the tank was read by the height of water in the transparent hose. A villager was assigned to take the reading every day and the reading was made in centimeters of water height. After the measurement, the stored water was released for the next measurement.

The observed water level data in the water storage tank and the volume of spring water discharge are shown in Fig. I.3.3. From the result of spring discharge measurement in the First Field Work in 1994, it was supposed that water saved by installing water tap was 3 - 7 l/min and the water tank of 70 m^3 was filled up in one week to 10 days. As shown in Fig. I.3.3, the spring water discharge during the monitoring period (May to August 1995) was estimated as 7-15 l/min and the water tank was filled up in 3-4 days. It was necessary to consider the influence of direct runoff discharge from rainfall and around 2-6 l/min of direct runoff was roughly estimated based on the rainfall record and conditions of catchment area. It was roughly estimated that 4-5 l/min of spring water was saved with installation of water tap. This rough water balance study is summarized below;

Water Balance at Phangyul Experimental Facility

Description		Estimated Discharge (l/min)
Inflow to Tank		7 - 15
Direct Runoff from Rainfall		2 - 6
Estimated Spring Discharge		5 - 9
Discharge for Domestic Use	without Tap	4 - 8
	with Tap	1 - 2
Expected Saved Spring Discharge		3 - 6

There was not enough data for this kind of analysis and it is necessary to observe the parameters continuously at least for more than 5 years.

2) Use of the Saved Water

When the stored water is released after measurement, the released water can be used for domestic and irrigation purposes. There are about 20 people (4 households) utilizing this spring water.

Discharge outflow of the tank is proportional to the water level in the tank. When the valve was fully opened, the discharge was found to be 15-28 l/sec and the discharge lasts for a period of 40min. Capacity of the existing channel is found to be 6-7 l/min and when the valve is fully opened, the channel will overflow. The tank operation was carried out by controlling the tank valve in proportion to channel capacity, and the storage water was utilized in 3-4 hours. The corresponding valve opening ratio and the discharge rate was found to be 50% and 5l/sec respectively. Domestic water was consumed for 3 times, morning, afternoon and evening for a total of 3 hours and the spring water was stored in the tank during some other time. Quantity of water utilized for different purposes at the various time periods is shown below:

Water Tap for Domestic use

Description	Operation Time (hr)	Estimated Water Amount (litter)	Estimated Water Amount (l/min)
Morning Time	0.5-1.0	60-100	1.0-2.0
Afternoon Time	1.0-2.0	60-200	1.0-1.8
Evening Time	0.5-1.5	30-150	0.7-2.0
Total	2.0-4.0	200-300	-

Storage Tank for Supplementary Irrigation Purpose

Operation Interval (day)	Estimated Discharge (m3/day)	Estimated Discharge (l/s for Operation Period)	Average Command Area (ha)
3-6	10-20	20-30	0.3

Although the monitoring survey was carried out mainly during the rainy season (May to August), water stored was also used to irrigate rice. During the planting season, the stored water was utilized supplementarily in addition to rain and canal water. In this area, villagers face water shortage especially during the planting season.

I.3.3 Evaluation and Recommendation

(1) Evaluation of System

Existing utilization of domestic water and irrigation water depend on the spring water, Bajo canal and rain water. The spring water facility was constructed to store spring water during the unused time. The quantity of water available in the storage tank is not sufficient for irrigation purpose. However, the water availability was increased by the storage in the tank and the water flow was observed until the end point of the canal. The water stored in the storage tank is controlled by the villager, which created a consciousness among the villagers to store and consume the water economically.

The valve control of the tank is carried out depending on the lower channel capacity. The functions of the storage tank which include the storage and control are recognized by the villagers. At present, the stored water is mainly used for domestic purposes. However, there is a possibility that the excess water can also be used for livestock and garden farm.

Since the time available for construction was limited during the monitoring study, panel tank was used for the storage tank. However, using the construction facility and materials available in Bhutan, the storage tanks of wet masonry can be constructed.

Since the storage of spring water is important to prevent the erosion of the farm land and to improve the standard of living of the farmers, another swamp area shall be selected for storing the spring water.

(2)Recommendations of the Future Planning

Based on the results of the monitoring, and considering the construction cost, it can be concluded that the direct benefit of the facility is quite a few from an economical view point. However, as discussed above, several uncountable benefits shall also be achieved.
Spring water storage facilities are desirable for the improvement of standard of living of the villagers and the environment. In future, similar type of spring water storage facilities shall be constructed to conserve and utilize the spring water effectively.

In planning the spring water storage facilities, the following items should be should be considered :

1) Planning of the Spring Water Storage Facilities

a) Investigation for planning

Planning of the spring water storage facilities shall be made as shown below.

Since the facilities are installed in the high hilly area where the land use is limited by its topography, the construction of these facilities shall be restricted to the areas which have good soil and topographic conditions.

The following investigations shall be made in order to design these facilities:

- Discharge of spring water
- Existing landuse conditions
- Existing conditions of water use
- Topographic conditions

b) Scale and Structure of the Tank

Decision of the volume of the storage tank is made in accordance with spring water discharge, soil and topographic conditions.

- The scale of storage tank must be decided considering the available volume of spring water, and water use. In case, a large scale tank is selected for storage of spring water, economic evaluation of water use should also be made.

- It is difficult to construct the storage tank on a swampy area, and therefore replanning of the site becomes necessary. If it is unavoidable, it is preferred that the method of burying half of the tank inside the soil shall be applied.

The main items of facility for the future planning are concluded as follows :

- Intake Facility

In order to prevent the percolation and seepage losses of spring water, the intake structure shall be made of wet masonry concrete to collect the spring water. Since the spring water is used for domestic purposes, the intake facility should be designed to prevent the accumulation of sediments during the rainy season. Besides, the intake facility should also be covered with a concrete board to prevent the falling of leaves and other materials.

- Water Collection Ditch

Water collection ditch shall be used for the multipurpose of conveying the spring water from the intake facility to the tank and to collect the run off water from the surrounding area. In order to collect the runoff water from the surrounding wet areas, the upstream side the collected ditch shall be constructed with dry masonry. The downstream side of the collection ditch shall be made of wet masonry in order to prevent the seepage losses.

- Storage Tank

The storage tank is the large scale equipment of the spring water facility and site of the tank is dominated by the topographic and landuse conditions. Since the main source of the facility is spring water, the soil conditions of the area is not suitable for setting the tank. In this Study, the tank was placed in the swamp area considering the land use and topographic conditions. The soil conditions in the area was not suitable for setting the tank and the soil consists of clay. Considering the clayey soil conditions of the swampy area and the limited time available for construction, panel tank was chosen for the storage tank.

However, where it is possible, the storage tank shall be made of wet masonry concrete by the available construction materials and method. Accordingly burying half of the tank inside the soil shall be applied.

I.4 Subsurface Water Scheme : Shallow Well Pumping Facility in the Bajo Area

I.4.1 Summary of Facility Plan

(1) General Condition

The utilization of subsurface water is also considered important especially in the areas along the rivers such as the Chang Chhu. To utilize the subsurface water effectively, a shallow well is dug in the northern part of the Bajo sub-area. The utilization of subsurface water is considered as one of the effective methods to provide irrigation and domestic water in the country, if such shallow wells are operated and maintained in good condition.

The subsurface water lifted up is expected to be used not only for domestic water supply but also for supplemental irrigation and emergency water source when the irrigation canal is damaged by hazards such as land sliding during the rainy season.

(2) Proposed Component of the System

A shallow well was excavated at the old river course of the Chang Chhu in the lower river terrace of the Upper Bajo sub-area. To facilitate the smooth construction, the liner plates with 3.5 m dia. was applied for the shallow well. The water collected in the shallow well is lifted up with a diesel engine pump and conveyed to the existing canal for irrigation through delivery pipe.

(3) Design Conditions

The following conditions were considered in designing the Shallow Well Pumping Facility in the Bajo Area.

1) Shallow Well

a) The shallow wells are generally made of reinforced concrete pipe or masonry work to save the construction costs. Steel liner plates was adopted for constructing the well in the Study taking into account of the limited study period. The subsurface water flows into the well through the holes provided on the wall or from the bottom of the well, and then is lifted up with any means.

b) Well diameter and depth were determined to be 3.5 m and 7.0 m, respectively as a result of preliminary study of the well dimensions and stability.

c) According to the above preliminary study on well, about 700 l/min of yield was expected.

d) Diversion Box

2) Lifting up Equipment

The diesel engine pump of 700 l/min was adopted for lifting up the collected water considering that the pumping equipment would be essential in performing the pumping up test of the well to be made periodically during the monitoring stage.

3) Delivery Pipeline

A delivery pipeline and a division box are provided to convey the lifted water to the adjacent field for irrigation in case such emergency or supplementary irrigation water is required. Four (4) inches diameter of PVC pipe was applied.

(4) Principal Features of Facility

The principal features of the constructed facilities are summarized below, and the general plan and layout plan of the proposed facility are shown in Fig I.4.1 and I.4.2.

1) Shallow Well

- Size of Well : 3.5 m
- Depth of Well : 7 m
- Material : Steel liner plate

2) Pumps

- Type : Single suction volute type (Movable)
- Capacity : 700 l/min
- Engine : Diesel engine

3) Delivery Pipe

- Pipe Material : PVC pipe
- Length : 90 m
- Diameter : 4 inches

4) Division Box

- Structure : Concrete

I.4.2 Monitoring Works for Subsurface Water Scheme

A shallow well was constructed in the old river course of the Chang Chhu as an experimental facility to utilize subsurface water. The purpose of the facility is to provide domestic water to the local people in the vicinity and to supply irrigation water to the cultivated lands extending around the well site.

(1) Purpose of Monitoring

The utilization of subsurface water is considered to be one of the most effective and popular measures to exploit the water resources. There are a lot of places along the rivers of the country which are suitable for this kind of measures, and the data and information obtained through this monitoring are believed to contribute for the application of shallow wells in the other similar topography of lands. Therefore, the purpose of this monitoring is to examine and confirm the technical feasibility, applicability and suitability of applying the shallow well in the Study Area and other similar areas.

(2) Monitoring Work

After the construction work was completed at the shallow well site in Upper Bajo area, the monitoring work was carried out from April to August, 1995.

The following items were monitored to evaluate the performance and adaptability of the facility:

- River and Well Water Levels
- Pumping Test Data of the Shallow Well

1) River and Well Water Levels

It is important to grasp the source and working of subsurface water for the shallow well. Since working of the subsurface water shall be related to river water and ground water, the subsurface water was observed by observation of daily water levels between the Chang Chhu and shallow well. Results of the monitoring are explained below :

The relationship between the water levels of the Chang Chhu and the shallow well is shown in Fig. I.4.3. Since the river water level was observed to be higher than the well water level, it can be concluded that the ground water terrace of the Bajo area does not influence on well water level. Accordingly, the water level of the well is influenced only by the water level of the river.

Water level rose three times, July 15, July 30 and August 14 and the time lag of each fluctuation was observed as 15 days. The difference of water levels is smaller during the summer season in the range of 10 to 20 cm and is higher during the winter season in the range of 50 to 60 cm. Based on the water level difference, the influence of river water level on the well water level is gradual. Fluctuation of water level from rainy season to dry season occurs in 15 days interval as observed during this study.

The relationship between the water levels of the Chang Chhu river and the shallow well was confirmed through the head difference between the water levels of the well and the river. Shallow well is recharged by the subsurface water from Chang Chhu river.

2) Pumping Test Data of the Shallow Well

The pumping test was conducted at the shallow well to grasp its hydrogeological conditions, which greatly influence on the suitability of the shallow wells installed at the site and the possibility of construction of the shallow wells.

Two types of pumping tests namely continuos pumping test and recovery test were conducted. The continuos pumping test was carried out for 12 hours period. The recovery test was carried out immediately after the completion of the constant discharge test. The pumping tests data are shown in Table I.4.1 and the results of the pumping tests are shown in Fig. I.4.4.

3) Estimation of Well Capacity by Size

Intake capacity is proportional to the radius of the well and its drawdown. The capacity of the well is calculated for each size of the well and drawdown for the utilization of shallow well. Intake capacity is calculated using the following formula and aquifer parameters from pumping test :

Intake Capacity (Q)

$$Q = S\,T / 0.0793\,W(u)$$

where Q is the Intake Capacity (m^3/sec)
T is the Transmissivity coefficient (m^2/sec)
S is the drawdown (m)

W(u) is the Well function of u

T and S value of above formula is obtained the continuous pumping test. It is important to grasp the hydrogeological conditions for well capacity, and the major parameters necessary are transmissivity and storage coefficient of the aquifer. These parameters are calculated by using the Thies's method and Jacob's method.
Thies's and Jacob's method is shown below and major parameters are calculated using the data of the pumping test :

a) Estimation of aquifer parameters from Pumping Test

i. Transmissivity Coefficient T

- Thies Method

Fig. I.4.5 shows the relationship between drawdown of the shallow well and time of the continuos pumping test. This Figure is overlapped with the Thies's type curve I in Fig.I.4.6 by the well function ($W_{(u)}$) and 1/u and the match point is obtained.

The parameter, which is Transmissivity coefficient T, is calculated by the following formula :

Transmissivity coefficient (T)

$T = 0.0796 \times Q/S \times W_{(u)}$

where T is the Transmissivity coefficient (m^2/sec)
Q is the Pumping rate (m^3/sec)
S is the Drawdown (m) by the S-r^2/t type curve

$W_{(u)}$ is the well function of u
$u = r^2 S / 4Tt$
r is the radius of the shallow well

$T = 0.0796 \times Q/S$
$= 0.0796 \times 0.016/0.59 \times 1 \times 0.00216 = 2.16 \times 10^{-3}$ m^2/sec

- Jacob's Method

Transmissivity coefficient is calculated by the following formula.
Drawdown (S) and time (t_o) at point S=0 are calculated using S-t Curve of Fig. I.4.5.

Transmissivity coefficient (T)

$T = 0.183 \times Q/\Delta s$

where T is the Transmissivity coefficient (m^2/sec)

Q is the Pumping rate (m^3/sec)
Δs is the drawdown on one logarithmic cycle > log(t/t')=1

$T = 0.183 \times Q/S$
$= 0.183 \times 0.016/1.036 = 0.00283 = 2.83 \times 10^{-3}\ m^2/sec$

- Time Recovery Test

Since intake discharge of the well after pumping up is as same discharge as in pumping up, time recovery test is utilized to intake discharge of the well. Transmissivity coefficient is calculated using the following formula :

Transmissivity coefficient (T)

$T = 0.183\ Q/\Delta s$

where T is the Transmissivity coefficient (m^2/sec)
Q is the Pumping rate (m^3/sec)
Δs is the drawdown on one logarithmic cycle > log(t/t')=1

$T = 0.183 \times Q/S$
$= 0.183 \times 0.016/0.914 = 0.00320 = 3.20 \times 10^{-3}\ m^2/sec$

Theis and Jacob methods were used to calculate of these parameters and the results are shown below :

TRANSMISSIVITY COEFFICIENT (T)

Transmissivity Coefficient	Thies Method	Jacob Method	Time recovery test
T	$2.16 \times 10^{-3} m^2/sec$	$2.80 \times 10^{-3} m^2/sec$	$3.20 \times 10^{-3} m^2/sec$

Considering the safety factor, a Transmissivity Coefficient of $2.16 \times 10^{-3}\ m^2/sec$ was selected as the T value of the aquifer strata.

ii Storage Coefficient S

An observation well is necessary for calculating the storage coefficient S. However the observation well was not installed because of inexperience and insufficient time available for the construction. Accordingly, a general storage coefficient value is selected.
The storage coefficient S of various aquifer materials are given below, and aquifer material shall be classified as gravely sand considering the soil conditions in construction and the above T value.

STORAGE COEFFICIENT S

Storage Coefficient	Clay	Sand	Gravel	Gravely sand	Sandstone	Limestone	Granite
S	0.03	0.25	0.22	0.16	0.08	0.02	0.005

Parameters of aquifer in the old river course at Bajo is grasped as below.

-Transmissivity Coefficient : $T = 2.16 \times 10^{-3}\ m^2/sec$

-Storage Coefficient : S = 0.16

b. Estimation of Intake Capacity of Well Size

With regard to the possibility of well sizes, the intake capacity of the wells are examined for three well sizes of 1.0m, 2.0m, and 3.5m using the results of the pumping test. The intake capacity for each well size is shown in Table I.4.3 and are summarized below :

Well Diameter	Draw down			
	1.00 m	1.50 m	2.00 m	2.50 m
3.5 m	5 l/sec	7 l/sec	10 l/sec	12 l/sec
2.0 m	4 l/sec	6 l/sec	8 l/sec	10 l/sec
1.0 m	3 l/sec	5 l/sec	7 l/sec	8 l/sec

Difference of Ground level at shallow well and river water is 0.5~1.50 m in experimental facility, and it is possible to drawdown 3.0~4.0 m based on the topographic conditions of the area.
The observed average discharge is calculated as 16 l/sec for a drawdown of 1.65 m based on the cumulative flow meter from the pumping test. As shown in the above Table, the drawdown for a well of 3.5 m diameter with a well capacity of 7 l/sec is 1.50 m based on the aquifer parameters from the pumping test. Thus, the well capacity is proportional to pump capacity and drawdown, estimation of well capacity is given about 7 l/sec for 1.50m drawdown.

I.4.3 Evaluation and Recommendation

(1) Evaluation of System

Based on the result of monitoring of well capacity and construction in this study, the subsurface water is evaluated as shown below ;

The resource of subsurface water is classified as direct resource and indirect resource. Direct resource is ground water, river water etc., and indirect resource is rainfall and irrigation water. From observation of water levels of river and shallow well, it was found out that the subsurface water mainly consists of river water at the old river course in Bajo, and therefore the subsurface water can be utilized permanently during the wet and dry seasons.

During monitoring term, subsurface water from the well was utilized by the local people for domestic water and irrigation water. However, well capacity is too small for irrigation water with a discharge rate of 7 l/sec for a drawdown of 1.50 m. Consequently, shallow well can be utilized as domestic water and supplemental irrigation water in damaged canal Bajo and during successive no-rain days for irrigation.

The construction of the experimental shallow well is described below ;

Heavy equipment and drainage pump were kept ready for construction of the shallow well considering the short construction term. However, since the soil conditions of the construction site consisted of silty sand and gravely sand, smooth construction was necessary to prevent from collapsing along the slope due to weak bearing capacity. The soil conditions is variable from site to site. The well frame was fabricated in the excavated hole, but inflow of the subsurface water was high and therefore a liner plate was fabricated on the ground and was hanged down by the heavy equipment. For constructing shallow wells, heavy equipment is necessary for smooth construction of all the well sizes and lengths.

(2) Recommendations for the Future Plan

Based on this study of the shallow well the following recommendations are made;

The resource of the shallow well is subsurface water based on the river water, and shallow well is available permanently for water resources development. Well capacity considering well size in this site is shown in Table.I.4.3 and drawdown and well size are important for the planning of the well. Drawdown depends on the topographic conditions, which is the head difference between river water level and ground of well. Accordingly, well capacity is proportional to topographic conditions. In all cases, well capacity for each size of well is too high for domestic water use alone. The shallow well shall be applied for public facilities, such as school, hospital and offices and can also be used for supplemental irrigation. Accordingly, it is desirable to plan the shallow well considering other uses of the well.
As mentioned above, heavy equipment and drainage pump is necessary for the construction of shallow well. And to facilitate smooth construction, ready made materials, such as liner plate and steel pipe are necessary. However at present, it is difficult to arrange construction materials and equipments in Bhutan. These arrangements should be made before the construction of shallow wells.

In the future, when subsurface water is used as the main water resource, use of the shallow well is indispensable. In the planning and construction of shallow well, the items of main equipments should be considered.

1) Intake location

The intake location shall be decided as follows :

-Investigation of intake location and the aquifer parameters

Subsurface water level and aquifer parameters vary at the various locations of the different water courses. Especially the Chang Chhu river has much sediment loads which are piled up during flood conditions. For comparatively shallow wells of 8~10 m depth, the soil conditions vary highly from fine sand to gravel at the intake location. The conditions of the soil layer for well capacity and construction must be confirmed by test boring.

-Subsurface water level

Based on the setting of shallow well, the available subsurface water level is an important parameter, for well capacity, pump specification and setting of the pump. In the shallow well, well depth is decided based on the topographic conditions and usual height of drawdown.

Subsurface water level depends on the fluctuation of river water level, and drought water level. The minimum intake capacity is determined in accordance with these items and the shallow well should be set as much close as to the water route of the river.

2) Structure of Well

The liner plate (ready made materials) was applied to facilitate the smooth construction considering construction term. Based on this study, ready made materials shall be adopted in the construction of the shallow well considering the following reasons :

-Joining and fabrication of the well frame is smooth
-Strength of well is satisfactory for the high stress

Regarding setting the well, there is a fear that the sand layer of the aquifer slip into the well or driven up during the intake operation. Layers of small size pebbles (2~3 cm), medium size pebbles (3~4 cm) and large size pebbles (4~5 cm) shall be laid for a thickness of 30 cm each to prevent this caving problem.

2) Diameter of the Well

Well capacity is variable by aquifer parameters, well size and drawdown. Since aquifer parameters and drawdown are restricted from topographic and hydrogeological conditions, well size is decided considering water demand.

3) Construction

Well construction can be classified into two methods. In the first method, the well construction shall be carried out by digging a big hole and then placing the well frame of ready made materials, vertically inside the well hole. In the second method, a hole is dug to place one frame and well is lowered down and then is dug again to place the second frame over the first frame and this process is continued until the desired depth. In this method, it is difficult to attain the vertical condition of the well and therefore this method shall not be applied. In the first method, the excavation shall be carried out using the excavator. For this purpose and smooth construction, the soil conditions and the structure of the aquifer stratum must be clarified.