2) Required Staff

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

The required number of the staff and local people assigned for monitoring works of experimental facility is tabulated in the table.

Staff Number Requied for Monitoring Works

Experimental Facility	RNRRC 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

4.2.2 Groundwater Scheme : Water Supply Facility of Deep Well in the RNRRC in Bajo

(1) Summary of Facility Plan

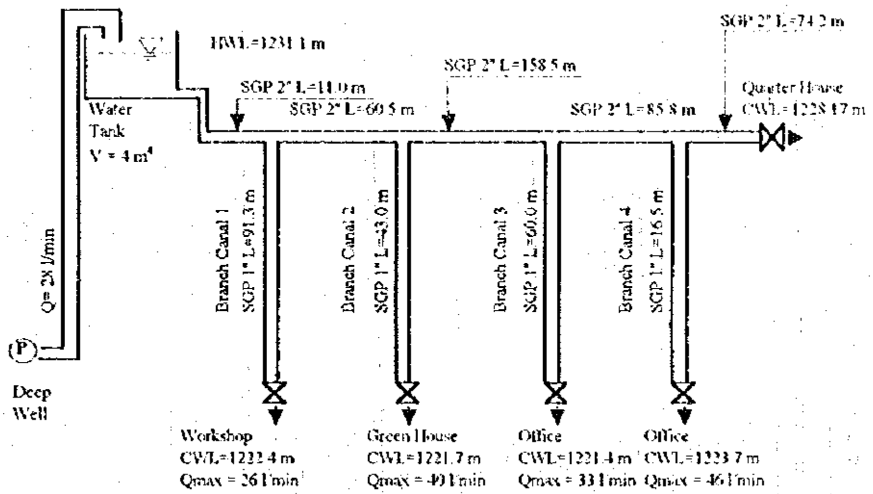
1) Basic Condition

The deep well water supply facility was constructed in RNRRC in Bajo utilizing the test well TB-3. 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 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, etc. so far, and is functioning well in good condition. Therefore, this power system is considered to be one of the recommendable measures to attain sustainable development in the water resources development sector too.

From the result of the meteo-hydrological study, 5.4 hr/day of average sunshine hour can be expected in the Wangdue Valley. The large amount of electric power cannot be expected from the solar system, and then, in most cases, this system may not be applied for the large scale of facilities like 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 like small water supply 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 RNRRC. To ensure the daily operation of pumping facilities even in cloudy or rainy days, the system is connected to the public electric power supply networks. The schematic diagram of the system is shown below.



SCHEMATIC DIAGRAM OF GROUNDWATER SCHEME

3) Design Condition

Based on the results of the field survey, the following conditions were employed in designing the facility.

a) Population Served	:day time 50 people, night time 20 people
b) Design Water Demand	: 160 l/person/day
c) Design Capacity of Elevated Water Tank	:4.0 m^3
d) Design Conditions of Solar System	
i) Average Sunshine	:5.4 hr/day (approx. 4.3 hr•Kw/m^2/day)
ii) Total Head	:50 m
iii) Pumping Capacity	:8 m^3/day
iv) Casing Pipe Diameter	:4 inches
v) Dynamic Water Level for Well	:30 m from ground level
vi) Type of Pump	:Multi-stage centrifugal submearsible pump with VVVF type inverter
vii) Electrical Specifications	
- Voltage	:3 x 65V
- Power	:550W, 0.75 HP
- Current	:8.8 A
- Power rate	:0.87
- Maximum Output	:1,200 W

4) Principal Features of Facility

The general and layout plans of the proposed facility are shown in Fig. 4.2.4. The principal features of the constructed facilities are summarized below.

a) Deep Well Pumping Unit
   i) Submersible Motor Pump
      - Type of Pump :Multi-stage centrifugal sub-mearsible pump
      - Casing Pipe Diameter :4 inches
      - Total Head :50 m (Dynamic water level GL-35 m)
      - Pumping Capacity :8 m^3/day
   ii) Electrical Specifications
      - Voltage :3 x 65V
      - Power :550W, 0.75 HP.
      - Current :8.8A
   iii) Control Panel :controlling facility for shifting operation from solar-driven to power supply-driven and vice versa.
   iv) Solar Array :nominal output voltage 65V DC

b) Existing Electric Power Supply
   - Power Source :440 V, 50 Hz, 3 Phases
   - Additional Power Line :Approx. 60 m with 2 electric poles

c) Elevated Water Tank
   i) Storage Tank
      - Capacity :4 m^3
      - Dimensions :2 (L) x 2 (B) x 1(H) m
      - Material :SMC panel tank
   ii) Tower
      - Height :6 m
      - Material :Steel structure
   iii) Distribution Pipes
      - Material :Galvanized steel pipe
      - Lengths and Diameters :390 m (2 in. dia.), 230 m (1 in. dia.)
   iv) Ancillary Facilities
      - Public Water Storage Tank :1 unit (500 l.)
      - Public Water Tap :1 unit

(2)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.

- Daily sunshine hours

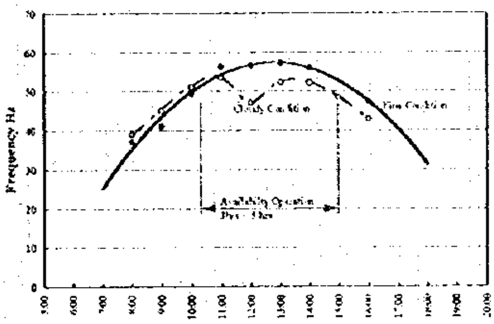
- Volume of water pumped up by solar power and electric power supply
- Relation of frequency and discharge by solar power driven pump

The results are shown in Appendix I and summarized below.

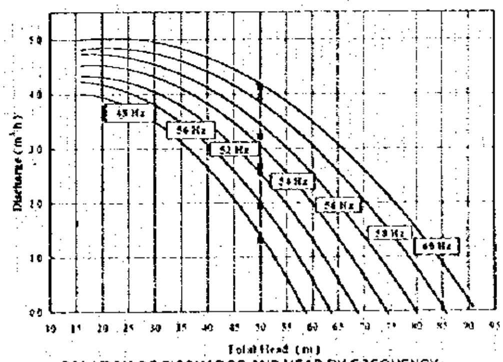
Average Yield by Type of electric Supply

(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)



CHARACTERISTICS OF SOLAR POWER GENERATION IN SUMMER



RELATION OF DISCHARGE AND HEAD BY FREQUENCY

The electric power generated by solar radiation varies depending upon weather conditions and sunshine hours. The figure presents the variation of the recorded electric frequency plotted together with the time. The frequency raises gradually after sun rise and at noon it reaches to the maximum. Since a frequency of more than 50 Hz is required for enabling the submersible motor pump to lift the water up to the tank, the functionable hour is five (5) hr and three (3) hour for fine and cloudy weather condition, respectively.

(3) Evaluation of System

For the water supply, this is the first case of applying the solar powered pumping system in Bhutan and the monitoring period was only five (5) months in this Study. The system was roughly evaluated as described in Appendix I based on a few monitoring data, and are summarized below.

- Considering the weather condition of rainy season, a maximum yield of less then five (5) m^3/day is expected, but this amount is too small for irrigation purpose.

- From the result of alternative study based on the initial and O/M cost, it is expected that applying the solar power system will be more effective than using the public power line for pumping up depending on the site condition. However, further detailed investigation should be required.

- To apply the solar system in Bhutan widely, it is necessary to solve the difficulty in purchasing spare parts, for which it may take a few months. Further the maintenance works require skilled technicians also.

- For the effective water use, it is necessary to consider the optimum storage tank capacity based on the water demand, capacity of well and site condition. It is essential to educate local people to control water taps for saving the costly pumped water.

4.2.3 Spring Water Scheme : Spring Water Storage Facility in Phangyul Area

(1) Summary of Facility Plan

1) General Condition

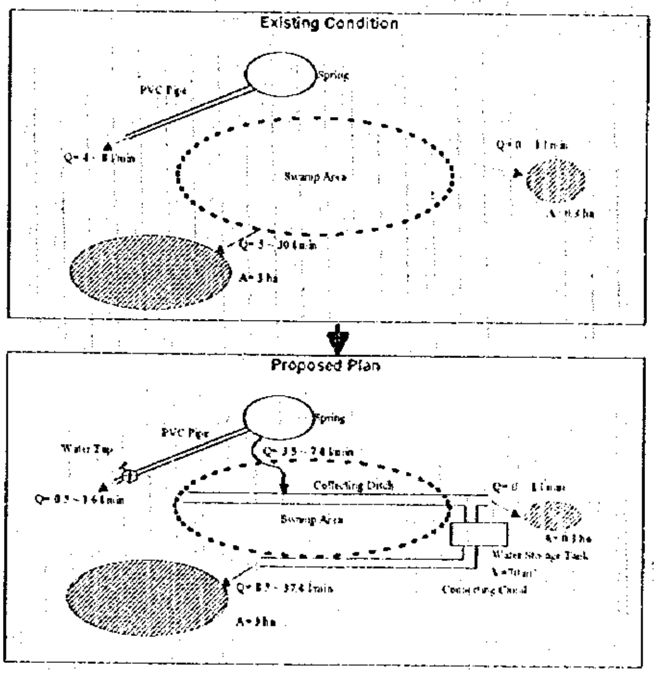
Reliable water source is quite scarce in the Phangyul area. Although most of the mountain springs in the Phangyul area is utilized to the maximum extent, villagers still have to face water shortage troubles in both of rural and irrigation water supplies.

In this area it is 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, a water tap was proposed to be installed 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 preliminary study, 5 to 15 % of increased water is expected to be created by applying a water tap and a storage tank.

2) Proposed Component of the System

As shown below, the system was proposed to be composed of water tap at the outlet of polyethylene pipe, a storage water tank, and a collecting ditch.



SCHEMATIC ILLUSTRATION OF SPRING WATER SCHEME

When the water tap is closed, the spring water is 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

Based on the results of field survey, the following conditions were considered in designing Spring Water Storage Facility in Phangyul Area.

a)	Water Tap	: An ordinary type
b)	Collecting Ditch	: Dry masonry type
c)	Storage Tank	: 70 m^3, SMC panel

4) Principal Features of Facility

The principal features of the constructed facilities are summarized below, and the general and layout plans of the proposed facility are shown in Fig. 4.2.5.

a) Intake Facility	
i) Spring Water Collecting pit	: Stone masonry
ii) Collecting Ditch	: Length 35 m, Hight 0.4 m, Botom width 0.4 m
b) Water Conveyance Canal	
i) Earthen Ditch	: Length 15 m, Hight 0.4 m, Botom width 0.4 m
ii) Stone masonry Canal	: Length 25 m, Hight 0.4 m, Botom width 0.4 m
iii) Desilting Pit	: 1 unit
d) Storage Tank	
i) Capacity	: 70 m^3
ii) Dimensions	: 6(L) x 6(B) x 2 (H) m
iii) Material	: SMC panel tank
e) Related Structure	
i) Wash Basin	: 4 m^2 (concrete)
ii) Delivery Pipe	: 3 inches, 20 m, PVC

(2) Monitoring Works

The monitoring works was carried out from the beginning of May to the end of August, 1995 except 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.

- Daily Rainfall at Phangyul
- Volume of Spring Water Saved by Installing Water Tap
- Use of the Saved Water

The monitring result is explained in the Appendix E and summarized below.

Water Balance of Phangyul Experimental Facility

Description		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

Summary of Operation Records at Spring Water Facility
(May to August in 1995)

(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
After Noon 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 (m^3/day)	Estimated Discharge (l/s for Operation Period)	Average Command Area (ha)
3 - 6	10 - 20	20 - 30	0.3

(3) Evaluation and Conclusion

According to the rainfall record, the rany season was started at the end of May in this year (1995), and it is necessary to consider the influence of the direct runoff of rainfall in the analysis of monitoring data. The facility was evaluated as summarized below, and the detail discussions are made in Annex I.

1) Effect of water tap

The amount of water saved with istallating of water tap is estimated as 3 ~ 6 l/min (approximatery 5 m^3/day), and this amount is equivalent to 10 ~ 15 % of total spring discharge. Considering the command area and the water requirement in the dry season, this amount is too small to use for the irrigation purpose. However, depending on the cropping period and weather conditions, even small amount of water is considered helpfull for the crop yield as the emargency supplemental water.

2) Effect of Storage Tank

Since wide flat spaces are found scarcely and the foundation is considered wet and weak in hilly areas, it is quite difficult to construct the storage tank with the capacity more than 70 ~ 100 m^3. This water amount is equivalent to the water requirements of one day for upland crops with only about 1.5 ha. According to the operation record, it took as long time as 3 or 4 days for filling it up in the rainy season, and it is estimated to take 7 to 10 days in the dry season. Therefore, the water of storage tank could be considered only as a supplimental resource for irrigation.

The spring water discharge is estimated at 0.1 to 0.6 l/s only, and there was not enough dischage head to reach to the end point of each lateral canal. Applying the water of storage tank, the maximum discharge as large as about 30 l/s becomes available, and the water reaches the end points of canals where any water had not been able to reach before the construction of the tank. From the results of fild survey, the farming practice was changed after the construction of tank. Futhermore, the new water users' group was formed and the manner of water management was determined through the discussion among the members of such users' group.

3) Effect of Collection Ditch

Before construction of collection ditch, the dump area was quite muddy, and was not used for any kind of purpose. After construction, such damp area was dried up even in the rainy season, and hence this area would be able to be used for agriculture.

Considering the construction cost, the benefit of this facility is quite a few from the economical viewpoint. However, the several uncountable benefits as mentioned above would be expected.

4.2.4 Sub-surface Water Scheme :Shallow Well Pumping Facility in the Bajo Area

(1) Summary of Facility Plan

1) General Condition

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

The sub-surface 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 dug at the old river course of the Chang Chhu in the lower river terrace of the 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

Based on the construction condition explained in Appendix I, the following design conditions were applied.

a) Shallow Well Capacity : 700 l/min
b) Lifting up Equipment : Total Head 25 m
c) Delivery Pipeline : Length 90 m

4) Principal Features of Facility

The general and layout plans of the proposed facility are shown in Fig. 4.2.6, and the principal features of the constructed facilities are summarized below.

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

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

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

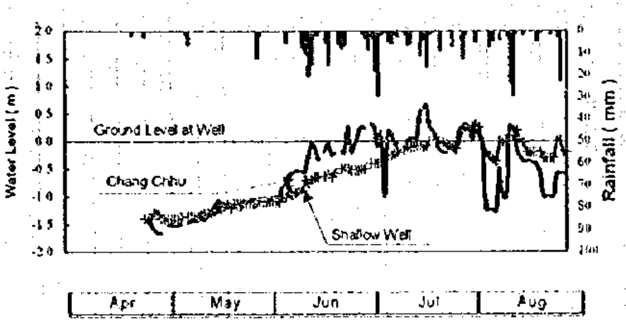
d) Division Box
- Structure : Concrete

(2) Monitoring Works

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

The result of monitoring are shown in Appendix I, and its summary is presented in the figure.



WATER LEVELS OF THE CHANG CHHU AND SHALLOW WELL

Summary of Result of Pumping Test

Methods	Thies Method	Jacob Method	Time Recovery Test
Transmission Coefficient T	2.16×10^{-3} m^2/sec	2.80×10^{-3} m^2/sec	3.20×10^{-3} m^2/sec

(3) Estimation of Well Capacity by Size

The following parameters were applied for estimating the well capacity based on the result of pumping test and site condition.

- Transmission Coefficient (T) : 2.16×10^{-3} m^2/sec
- Storage coefficients : 0.16 (Gravely Sand)

The detailed manner of estimation is described in Appendix I, and the results are summarized in the table.

Estimated Well Capacity

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

(4) Evaluation and Conclusion

Based on the results of monitoring and the experiences during the construction works, the shallow well facility was evaluated as described in Appendix I and the evaluation is summarized below.

1) Relationship of Water Level between the Chang Chhu and Well

The water level in the shallow well varies with the tendency similar to the Chang Chhu and the time lag was estimated as approximately 15 days.

2) Well Capacity

From the result of pumping test, the well capacity is expected at 3 ~ 12 l/s depending on the well diameter and draw down. Considering the maximum water requirement of the Bajo and the Lobeysa sub-areas, about 3 ~ 12 ha of paddy fields could be irrigated.

3) Difficulty in Construction

It is necessary to find out the old river course for the construction of shallow well and, in most cases the soil condition of old river course is considered to be gravely sand. Considering this soil condition, it is necessary to use the heavy equipment for the construction, because the depth of well would be about 10 m.

4) Economical Condition

From the results of alternative study described in Appendix II, the shallow well systems are not feasible for irrigation purpose considering the balance of cost and benefit.

Consequently, the shallow well system should be considered as one of the water resources for domestic use.

4.2.5 River Water Scheme : River Pumping Station in the RNRRC in Bajo

(1) Summary of Facility Plan

1) General Condition

In Bhutan, the surface water exploitation is considered to be the most important measure for the developing water resources, and various surface water exploitation projects have been conducted so far. However, some of those projects have not implemented successfully especially in case of pumping scheme because of intrusion of sediment loads into the pumping equipment as well as the inlet structure. Such sediment intrusion is apt to result in frictional damages of impellers of the pumping equipment as well as obstruction to the water flow in pipes and canals. Huge amount of costs is necessary for removing such sediments load piled in and in front of the pumping station. In this connection, it is considered quite important and worth to develop and propose such type of pumping station that is believed to overcome the above troubles in pumping.

The river pumping was constructed in the flat yard beside the Chang Chhu to pump up the river water to the existing RNRRC irrigation facilities considering the above matters. In Bhutan, there are other rivers having the similar topographic conditions to the planned site. The similar type of pumping station may be able to be constructed in those other areas in the future. The structure and materials to be applied to this pumping station, therefore, should be those commonly available in the market of the country.

2) Proposed Components of the System

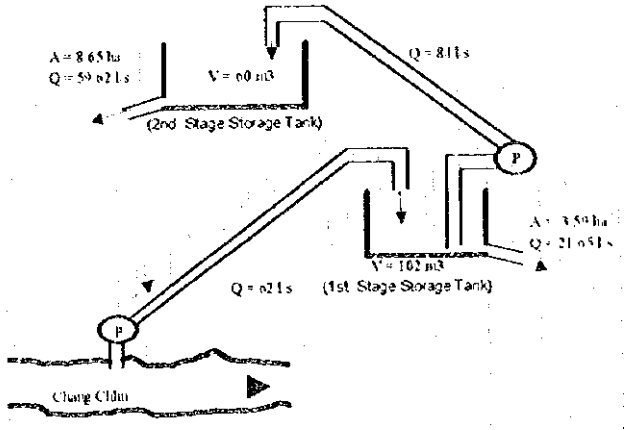
Based on the irrigation plan of the RNRRC farm yards, the pumping system plan was proposed as shown below.

The construction of the experimental facilities for RNRRC farm yards includes:

- the construction of slide type pumping station, and
- the connection of delivery pipe to the 1st. stage storage tank.

In determining the dimensions and sizes of facilities, it is necessary to pay so careful attention that the pumping station to be constructed should be of the structure not only to enable to solve the above troubles in pumping but also to function as planned together with the existing irrigation system in the farm yards.

A slide type of pumping station is, therefore, applied for the construction to solve the above-mentioned problems taking the following items into account.



PROPOSED PUMPING SYSTEM AT RNRRC

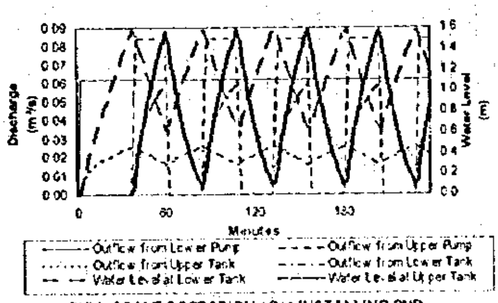
- The difference of water level of Chang Chhu river between dry season and rainy seasons varies from four (4) to five (5) m and the difference in suction head of the pump between these two seasons are very large. For minimizing the suction head losses, the pumping equipment should be moved on the inclined steel rail depending on the suction water level.

- In order to prevent the entry of sediment load directly from the river bed to the suction pipe and the pumping system and to avoid the frictional damages of the impellers, a floating type of suction was designed.

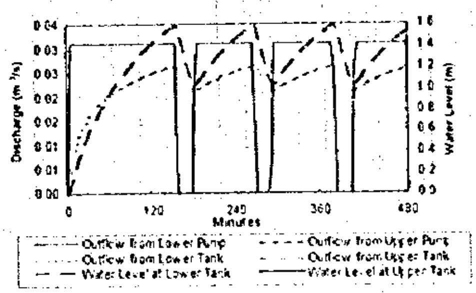
- Since the construction equipment and materials required for the under water construction is not available in Bhutan, the facilities were designed in such way that the construction should be carried out with the equipment under dry condition.

The pump units are not fixed on the ground since the pump units are moved on the inclined steel rail using the hand winch in accordance with the fluctuation of river water level. The suction hose is flexible and the suction strainer is floated in the river.

As for the pumping operation, a simple alternative calculation was carried out to work out the most appropriate pumping operation in the RNRRC farm yards as shown in the Data Book. As a result, the pumping operation shown below was proposed to attain the balanced operation utilizing the available facilities to the maximum extent.



FULL SCALE OPERATION after INSTALLING 2ND. STAGE PUMP



TENTATIVE OPERATION UNTILL 2ND STAGE PUMP

3) Design Conditions

The following conditions were considered in designing the River Pumping Station in the RNRRC Farm.

a) Irrigation area :12 ha
b) Design Capacity :62 l/sec
c) River Water Level and Pump Installation Level
  i) River water level
    - H.W.L (High Water Level) :TP 1,199 m
    - L.W.L (Low Water Level) :TP 1,194 m
  ii) Pump installation level :TP 1,196 m ~ 1,200 m
  iii) Suction water level :TP 1,194 m ~ 1,198 m
  iv) Farm pond water level
    - Discharge water level :TP 1,218 m
d) Number of Pumps :Two pump units
e) Pump Head
  i) Actual head :25 m
  ii) Pipeline losses :9 m
  iii) Total Head :34 m
f) Pipe line
  i) Pipeline length :270 m
  ii) Pipe :200 mm, PVC

4) Prinsipal Features of Facility

The general plan and layout plan of the proposed facility are shown in Fig. 4.2.7 and Fig. 4.2.8. The principal features of the constructed facilities are summarized below.

a) Intake Pumping Unit
  i) Intake Pump (2 Sets)
    - Type :Single suction volute pump
    - Capacity :1.88 m^3/min
    - Total head :34 m
  ii) Motor for Intake Pump (2 Sets)
    - Type :Totally enclosed, square cage
    - Output :18.5 kW
    - No. of poles :4 P
    - Voltage :415 V
  iii) Slide Base (2 Sets)
    - Material :Mild steel
  iv) Valves (2 Sets)
    Foot Valve :150 mm
    Sluice Valve :125 mm
    Non-return Valve :125 mm
  v) Suction Piping (2 Sets)
    - Flexible Pipe :150 mm
    - Connecting Pipe :150 mm x 125 mm

vi) Delivery Piping (2 Sets)

- Flexible Pipe : 125 mm
- Connecting Pipe : 100 mm x 125 mm
- Header Pipe : 200 mm / 200 mm / 125 mm / 125 mm

vi) Pump Control Panel (1 Set)

- Type : Outdoor, self-standing
- Starting Method : Star-delta
- Power Source : 415 V, 50 Hz

b) Concrete Base for Pump Sliding

- Concrete Base : 13.4 (L) x 5.8 (B) x 0.5 (T) m
- Slide Steel Rail : 2 Sets
- Hand Winch : 2 Sets

c) Revetment

- Gabion Work : 60 (L) x 15 (B) m

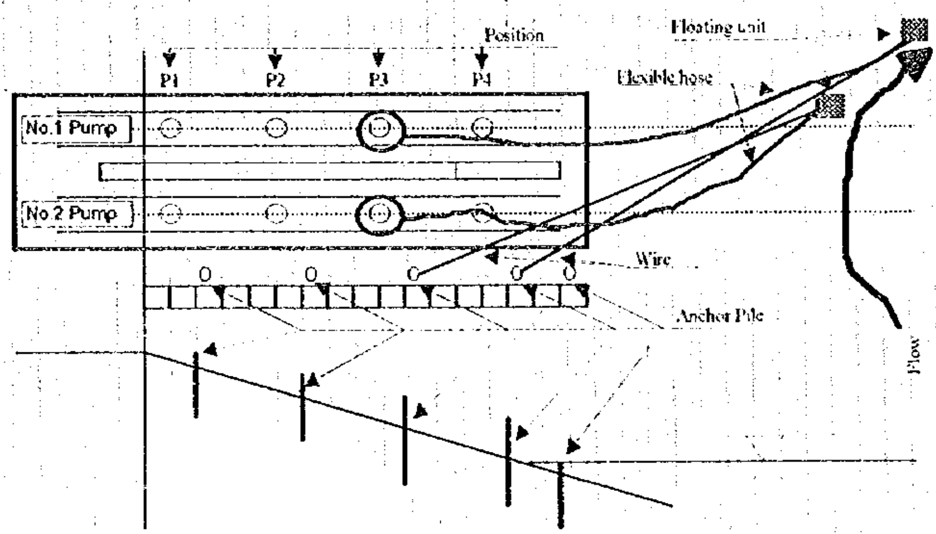
(2) Monitoring Works

Monitoring work of slide type of pumping station were carried out from the middle of July to the end of August in 1995. The detailed monitering items area explained in Appendix I, and the results are summarized below.

- Required time for pumping operation including positioning and setting up
- Pumping discharge with different suction head
- Condition of flexible suction hose and floating unit

1) Required Time for Positioning and Setting up

The layout of pumping position is illustrated below.



POSITION OF PUMPING EQUIPMENT

The result of monitoring is described in Appendix I, and its summary is tabulated below.

Summary of Required Time for Pumping Operation

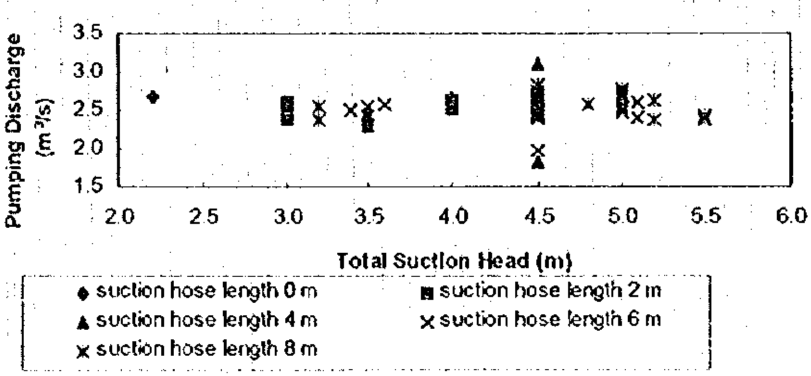
Description		Required Time (min)	Remark
Positioning	Pump unit	10 ~ 15	Pipe disconnecting for one unit
		15 ~ 20	Pipe connecting for one unit
		10 ~ 35	Sliding down for one unit
		15 ~ 30	Sliding up for one unit
	Floating unit	10 ~ 35	Lifting down for one unit
		10 ~ 60	Lifting up for one unit
Filling up water for suction pipe		20 ~ 30	for one unit
Total time for setting up		60 ~ 100	for one unit
Total time for resetting		70 ~ 90	for one unit

One supervisor and 5~6 supporting staff were required for positioning pumping units and 6 ~ 7 staff were required for floating units. The following reasons are considerd for this time cosumption.

- Weight of pump is 500 kg/unit and hence sliding of the pump is a heavy task.
- The weight balance of pump is not sutable for sliding operation, and then it is necessary to take a time for sliding carefully.
- It is relatively difficult to adjust both rails to fix the bolt between the rail and the pump stand keeping a stable and balanced position of the pump.
- Space between rails was relatively narrow for the sliding operation.
- Since a check valve for water hammer was attaced to one side of pump, the unit is not able to be moved in a balanced position.
- The weight of floating unit is 200 kg/unit and there is no equipment to lift it up. Furthermore, an flange joint made of iron connects the float and the pipe.
- Weight of flexible hose is heavy in proportion to its length.
- There is no foothold on concrete base and gabion

2) Pumping Discharge with Deffernt Suction Head

The monitoring data is shown in Appendix I and illustrated below.

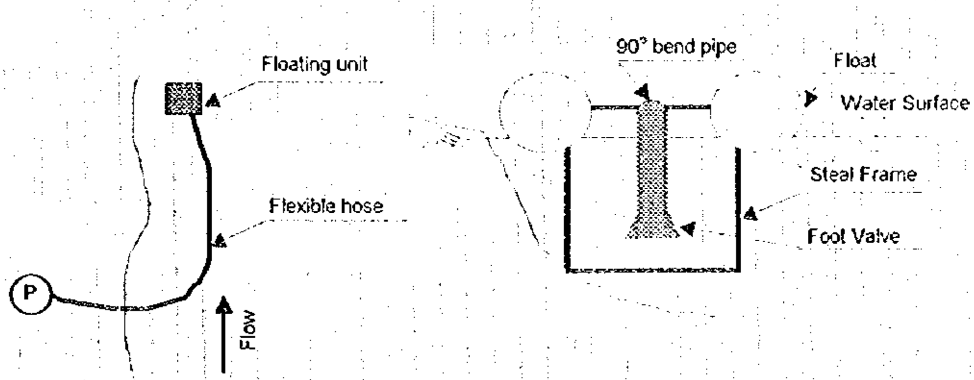


PUMP DISCHARGE AND SUCTION HEAD

From the results of monitoring described in Appendix I, it is possible to operate the pump with total suction head of 5.5 m (actual head: around 4.5 m), but it should be suggested to operate the pump with total suction head of less than 4.5 m (actual head: around 3.5 m) considering the cabitation and pumping load. Furthermore, the influence of head loss caused by the flexible hose was estimated at about twice of design head loss in suction hose. In the design stage, it is necessary to consider the suitable safety factor for suction head, if applying this type of pumping system. The length of suction pipe is also suggested to be more than six (6) m for stabilization of pumping discharge.

3) Condition of Flexible Suction Hose and Floating Unit

The floating unit consists of steal frame, float, foot valve and 90° bend pipe, and connecting at the tail end of the flexible suction hose. This floating unit is connected only with wire, and it has been always moved with river flow. However,the following unit was designed to prevent the unit from touching the river bed.



FLEXIBLE SUCTION HOSE AND FLOATING UNIT

The foot valve is inside the steal frame and the depth to the bottom is always kept in the optimum condition for sucking the water. From the results of monitoring, even if the tail end of flexible suction hose moves near the river edge, any kind of problem does not take place during the pumping operation.

(3) Evaluation and Conclusion

The system was evaluated as described in Appendix I, and the evaluation is summarized below.

1) Merit of Slide Type Pumping System

- Using the floating unit and flexible hose, it is possible to keep the optimum suction head against the variation of the river water level.
- It is not nesessary to consider the maintenance for sedimentation problem.
- There is no problem for pumping operation even if main river course is changed.
- The system can be established with small civil constrction works.

- It is not necessary to consider the protection works for the flood time.

2) Demerit of Slide Type Pumping System

- Considering the pumping operation including positioning and setting up, the large pumping unit will not be able to apply for this system. Therefore, if the system is applied for irrigation purpose of paddy field, the cammand area of 15 to 20 ha could be the maximum scale for one pumping station.
- In case of applying the electrical motor pump, 5 ~ 6 suppoting staff is always required for positioning, setting up and resetting the operation.
- From the results of alternative study described in Appendix H, the river pumping system is not economical if the system is only for irrigation purpose.

It is technically feasible to apply the slide type river pumping system in Bhutan, and this system is considered to be one of the alternatives for water resources development scheme. Based on the results and experiences of the study on and construction of the experimental facility, the several points for improvement are identified as described in Appendix I.

4.3 Sub-surface Water and Groundwater Resources

Within the Study area, significant volume of exploitable water resources comprising of sub-surface water and groundwater is explored. On the basis of mode of occurrence, groundwater can be classified into i) river terrace related groundwater, ii) landslide related groundwater and iii) mud-flow related groundwater.

The calculated water potential for each sub-area is summarized in the following table.

Potential of Available Water Resources in the Study Area

Sub-area	Sub-surface Water (l/min)	Groundwater (l/min)			Total (l/min)
		River Terrace	Landslide	Mud-flow	
Lobeysa	Nil	N/A	450	2,450	2,900
Bajo	1,000	800	400	N/A	2,200
Phangyul	N/A	N/A	1,000	450	1,450
Rubeysa	N/A	N/A	450	900	1,350

The total of potential derived from groundwater and sub-surface water resources in whole of the sub-areas are calculated to be 5,200 l/min. The methods of calculation and the basic conditions considered in calculating the above potential are briefly described below, and explained in detail in Appendix-D.

4.3.1 Sub-surface Water Potential

Large-scale underground water-flows running through gravel zones underneath of or nearby rivers are called "sub-surface water". These gravel zones usually represent ancient river channels. In some cases, water flows underneath present rivers are called "river-bed water". The terms of "underflow water" and "underground stream" are also used for this same meaning, but only "sub-surface water" is used in this report.

Sub-surface water is hydrogeologically connected directly with water of rivers or lakes, and can not be separated each other. Therefore, static water levels of sub-surface water are closely related to those of river water. Flow velocity of sub-surface water is normally slower than that of surface water, but significantly faster than that of nearby groundwater.

Accordingly, exploitable water potential of the sub-surface water in the area is extremely high due to the direct water supply from the river. The potential can be related with the volume of sub-surface water which is calculated by the following formula.

$$Q = A \times K \times I$$

where Q: flowing volume of subsurface water
A: area of cross section
K: coefficient of permeability
I: hydraulic gradient

In the Bajo sub-area, if width of sub-surface flow is assumed at 200 m, or one half that of low terrace width, and exploitable depth is assumed at five (5) m, then: A = 200 m x 5 m = 1,000 m^2. assuming a hydraulic gradient equivalent to that of the river gradient, or 1/150, and a coefficient of permeability equal to a standard gravel bed, or 2.5 x 10^{-3} m/sec, then:

$$Q = \frac{1,000}{150} \times 2.5 \times 10^{-3}$$
$$= 16.6 \text{ l/sec} = 1 \text{ m}^3/\text{min}$$

In conclusion, the area has quite high potential for exploitable water resources from the sub-surface water, and the actual exploitable volume will be decided by the number of wells and their depth due to its great recharge capacity.

4.3.2 Groundwater Potential

Because of the mountainous terrain, there is a wide variety of local groundwater conditions, nevertheless the hydrogeological condition of the Study area could be generalized as an area of two-layered geological model, i.e. impermeable basement rock layer and permeable Quaternary cover.

In the area of basement rocks, no important water yield is observed. The Quaternary covers in the Study area are composed of thickly weathered crest planes, river terraces, landslide debris, and less permeable mud flow deposits.

The Quaternary river terraces along the Chang Chhu are the most important aquifer in the area. Since the Study area is situated in the mountainous area, no impermeable layer is intercalated in the terrace deposits, suggesting that the groundwater in the area is unconfined.

Perennial yield of minor quantity of spring water is often observed at toes of landslides in the sloped area. The groundwater here is a sort of "perched groundwater" embraced in the slide debris and under-propped by the black colored landslide clay layer. The best yield of water comes from just above the black clay layers. These types of springs are the most important water source in the high elevated areas.

Although the mud flow deposits are less permeable, the huge volume of the massive sediments could be an excellent storage for groundwater. The groundwater retained in the mud flow deposits is concentrated in the bottom of the mud flow layers, specially depressed parts of the paleo-topographic relief, and may have good potential for the yield of water.

The groundwater in the area can be classified into the following three (3) categories.

- groundwater in river terrace deposits
- groundwater in landslide debris
- groundwater in mud-flow deposits

(1) Groundwater in River Terrace Deposits

The terraces in the area can be classified into five (5) levels. The deposits mainly consist of sands and gravel. No impermeable layer such as clay layers exists in the terrace deposits, therefore, all groundwater is unconfined and concentrated in the bottom of the deposits, just above the basement rocks.

Classification of Terrace

Terrace	Height from River Surface
H1:	approximately 130 meters
H2:	70 to 100 meters
M1:	30 to 50 meters
M2:	10 to 20 meters
L:	2 to 10 meters

Considering the depth of the bedrock from the surface, terraces of H1 and H2 are not adequate targets for groundwater development because of necessity of deep drilling and high cost for exploration and exploitation.

On the other hand, terraces of the L category are good areas for groundwater development because of its potential and easy prospecting. The way of development for groundwater in the category L terraces is discussed in the item of "sub-surface water". Only the groundwater in the M1 and M2 which are distributed in the Bajo sub-area will be discussed in the Study.

In the survey this time, the electric survey applying the Schlumberger method has been performed. The results revealed two zones in the M1 terrace showing a crescent-shaped low resistivity zones which suggest good potential for groundwater. Presuming from these shapes, the zones would be resulted from buried ancient river channels, which would had been formed during the time when the Chang Chhu river meandered over a width of several hundred meters.

Two (2) holes, TB-2 and TB-3, were drilled in the presumed buried channels. The depth of the aquifer is about five (5) m higher than the present river level. The chlorine content of the groundwater from TB-2 shows 30 ppm, and the spring water from Umtekha village in the mountainous terrain, about two (2) km north of the drilled area, shows 46 ppm. Therefore, it is presumed that the groundwater in the area is mostly recharged from the background mountain areas situated to the east as well as the Limit Chhu, adjacent to the north, running water of which shows 15 ppm in chlorine content.

Simply presumed if the water from the mountainous area, which contains 46 ppm of chlorine, is diluted by the water from the Limit Chhu, which contains 15 ppm of chlorine, it is estimated that the groundwater from TB-2 is composed of 50 % of water from the eastern mountainous area and 50 % of surface water from the Limit Chhu.

As mentioned above, the groundwater in the terraces is recharged from the background mountains and the surface water of the tributaries. The background mountains in the Bajo sub-area have an area of two (2) km^2. The volume of the recharging groundwater run-off in the area is estimated using the average 355 day's specific discharge in metamorphic rock terrains of 7.6 l/sec/km. It is presumed that the recharged water volume from the tributaries is about the same as that from the background mountains. Therefore, it can be estimated that the total recharge volume of groundwater in the Bajo sub-area is 1,800 l/min or 2,590 t/day. Exploitable volume may be about 40% of recharge volume as discussed in section (2) below. This amount, 800 l/min is sufficient for drinking water source in the middle and low terraces areas.

(2) Groundwater in the Landslide Area

Many landslides are observed in the area. Most of the cultivated flat terrain located in the middle slopes of the hilly areas has been formed by landslides. Small perennial springs yielding 5 to 20 l/min, are distributed in these slide areas.

The landslide debris in the area is a massive and highly porous unit, composed mainly of blocks or fragments of weathered rocks and lateritic soil. The physical character of the debris is excellent as an aquifer but the volume of each slide unit is too small to develop and utilize a large quantity of groundwater. These small-scale springs in the area are found in muddy marsh with black clayey material.

The groundwater kept in fractured landslide debris, therefore, might be under-propped by the impermeable bottom clayey layers, forming perched groundwater on the clay layers in middle slopes of the mountain areas.

The potential for development of water in the area is rather low in general because of its great variations of groundwater conditions due to its isolated, small-scale geological unit.

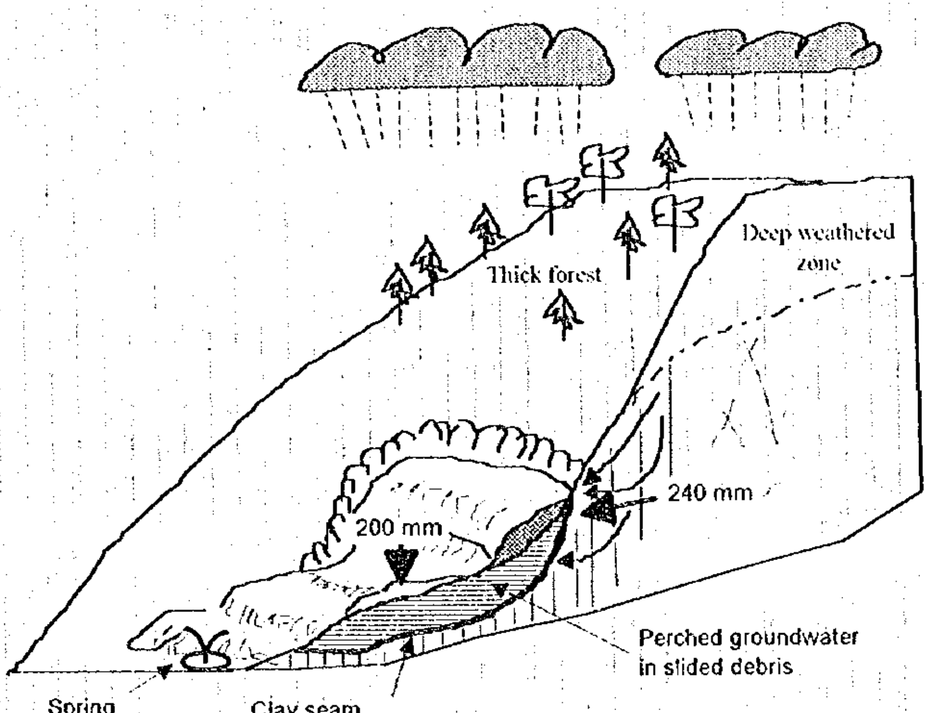
On the other hand, assuming if the scale of landslides is in proportion to the storage capacity of the groundwater, it is possible to estimate groundwater potential using the size of landslide landmass.

In the example of the spring of S6 in Phangyul, the water quantity in the dry season from October to April is about seven (7) l/min, and that in the wet season from May to September is about 14 l/min, so that its average figure is 10 l/min, 14.4 m^2/day or 5,256 m^3/year.

The scale of the mass of the landslide block is about 300 m × 300 m in the area, 15 m in average thickness, and 1,350,000 m^3 in its volume. Assuming its effective porosity is 10 %, it is estimated that its water capacity is 130,000 m^3. This means that the water capacity is abundant enough for its yield quantity.

It is estimated that the precipitation in the area is about 1,000 mm/year. Assuming that 20 % of the rain water, that is 200 mm/year infiltrates into the ground, recharge quantity is about 18,000 m^3/year.

In addition to this, some fracture water in the background mountainous area is expected as recharge sources. It is hard to estimate the volume of this, but its specific discharge per 0.09 km^2 is calculated based on the data that the 355 day's specific discharge in crystalline schist terrains in Japan, under similar geologic and meteorological conditions, is 7.6 l/sec/km². If all fracture water is recharged into the landslide block of 0.09 square kilometers, the quantity of recharged water is 21,400 m^3/year, or 240 mm/year. Accordingly, the total quantity of recharge water, from rain water plus landslide areas of the background mountains, is about 40,000 m^3, or 440 mm/year.



SCHEMATIC ILLUSTRATION SHOWING RECHARGE PATTERN IN LANDSLIDE AREA

This quantity of recharge water is the function of the area of the landslide block, and the quantity is calculated using the following formula.

Quantity of recharge water = Area of landslide block (m²) × 0.44 m

As discussed before, many small but perennial springs, genetically related to the landslide, are being utilized in many villages. This water in the slide debris is being recharged by precipitation as well as by seepage from the forested background mountains. Since the total volume of the debris is limited, the exploitable quantity of water is also limited. However, the water yield from these springs contributes only 13% of annual recharge. Accordingly, the yield quantity could be considerably increased, say up to 40% of recharge quantity, by trenching if it is done in the correct way.

(3) Groundwater in Mud-flow Area

Major mud-flow deposits are distributed in the Lobeysa area and several other small areas. The litho-facies of these mud-flow deposits are quite uniform in appearance. The rock fragments in the deposits vary from block-scale to fragment-scale, and are scattered in its brown muddy matrix. These facts suggest that a huge volume of materials saturated in water have been transported in a short time.

The groundwater retained in the mud-flow deposits is under-propped by the basement rocks, and may have a good potential yield for water at the zone just above the basement.

Two (2) drill holes, TB-4 and TB-5, were constructed in the mud-flow area. The optimal quantities for pumping in TB-4 and TB-5 are 110 l/min and 55 l/min, respectively. The catchment area for TB-4 is about 8 km^2 and the area for TB-5 is about 2 km^2. Mudflow areas are 2.5 km^2 for TB-4 and 0.14 km^2 for TB-5, respectively. Upon comparison of the optimum yield, catchment area and mud-flow area for each of the two drill holes, it is concluded that catchment area size is more significant factor controlling groundwater volume than either mud-flow area or volume. Applying the values set out in the previous section, specific discharge of metamorphic rock is roughly calculated at 7.6 $l/sec/km^2$ (450 $l/min/km^2$). If 40% of this is considered exploitable, then:

$450 \times 0.4 = 180\ l/min/km^2$

In other words, in the mud-flow area, 180 l/min of groundwater is exploitable for every one (1) km^2 of catchment area. These holes have been drilled in a buried creek suggested by the result of an electric prospecting.

These mud-flow deposits have completely covered the pre-existing topographic relief, forming new drainage or creek patterns which are entirely different from the buried drainage pattern. The groundwater in these areas, however, is still flowing down to the buried creeks as mentioned before. This is the main reason why dry creeks are often observed in the mud-flow areas.

4.4 Surface Water Resources

4.4.1 Available Surface Water Resources in Each Sub-Area

As presented in Table 5.1.1, there are 22 irrigation schemes in and around the Study area and 10 schemes of them function to supply the irrigation water to the sub-areas as shown in Fig. 5.1.1. The present conditions of water resources for 10 schemes are summarized below.

Summary of Water Resources for Irrigation Scheme in the Sub-Area

Sub-Area	Code	Name of Canal	Canal Length (km)	Water Source River	Water Source Catchment Area (km2)	Water Source Altitude (m)	Mean Discharge (m3/s)
Lobeysa	C1	Upper Lobeysa	7.1	Taberong	119.40	1,400	6.574
	C2	Lower Lobeysa	8.1	Chhu	119.40	1,380	6.574
Bajo	C9	Bajo	15.0	Pe Chhu	145.70	1,420	8.022
Phangyul	C10	Phangyul	16.0	Lachhu	2.23	2,330	0.123
	C15	Gemkha	3.5	Uship	0.84	1,750	0.046
Rubeysa	C18	Nalakha	3.9	Mochuna	8.78	1,440	0.483
	C19	Rutekha	2.2	Takarong	3.03	1,880	0.167
	C20	Maphekha	2.2	Chhu	6.23	1,760	0.343
	C21	Naykoyuwa	1.7		2.95	1,920	0.162
	C22	Romina	1.1		6.80	1,560	0.374

Based on the results of hydrological study, the river discharge at each intake site was roughly estimated as shown below.

Estimated River Discharge at Intake Site

(Unit : m^3/s)

River	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Taberong Chhu	2.602	2.500	2.327	3.231	4.034	8.028	12.453	16.755	13.577	6.067	4.286	3.029
Pe Chhu	3.175	3.051	2.840	3.943	4.922	9.797	15.196	20.446	16.568	7.403	5.230	3.696
Lachhu	0.048	0.047	0.043	0.060	0.075	0.150	0.232	0.312	0.253	0.113	0.080	0.056
Uship	0.018	0.017	0.016	0.023	0.028	0.056	0.087	0.117	0.095	0.042	0.030	0.021
Mochuna	0.191	0.184	0.171	0.237	0.296	0.590	0.915	1.231	0.998	0.446	0.315	0.223
Takarong Chhu	0.148	0.142	0.133	0.184	0.230	0.457	0.709	0.954	0.773	0.346	0.244	0.172

Furthermore, the river water of the Chang Chhu will be available for the Lobeysa and Bajo sub-areas applying the river pump system. Based on the hydrological analysis, the flow conditions of the Chang Chhu are summarized below.

Monthly Discharge at Chang Chhu (m^3/s)

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	85.0	82.0	94.4	143.6	231.2	479.1	596.9	598.3	497.6	313.0	151.3	108.3	281.7
Max.	95.3	91.9	129.4	308.7	318.5	692.2	965.9	881.5	697.0	427.4	190.4	126.8	965.9
Min.	78.9	74.1	74.0	97.0	156.0	279.8	376.0	416.0	330.2	205.9	122.7	91.9	74.0

Limti Chhu is one of perennial tributaries flowing into the Chang Chhu in the Bajo sub-area, but water cannot be expected to be available in this river because almost of the river water is used for the farm land in the upstream.

4.4.2 Surface Water Resources Potential

With a consideration of environmental conservation, at least 20% of the river discharge should flow down as the maintenance flow. Consequently, up to 80% of the river discharge can be considered as an available river discharge. Therefore, the potential of surface water resources was estimated as shown below;

Available River Discharge at Intake Site

(Unit : m^3/s)

River	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Taberong Chhu	2.081	2.000	1.862	2.585	3.227	6.423	9.963	13.404	10.862	4.853	3.429	2.423
Pe Chhu	2.540	2.440	2.272	3.154	3.938	7.837	12.157	16.357	13.254	5.922	4.184	2.957
Lachhu	0.039	0.037	0.035	0.048	0.060	0.120	0.186	0.250	0.202	0.090	0.064	0.045
Uship	0.015	0.014	0.013	0.018	0.023	0.045	0.070	0.094	0.076	0.034	0.024	0.017
Mochuna	0.153	0.147	0.137	0.190	0.237	0.472	0.732	0.985	0.798	0.357	0.252	0.178
Takarong Chhu	0.119	0.114	0.106	0.147	0.184	0.366	0.567	0.763	0.619	0.276	0.195	0.138

As for the available water of the Chang Chhu, it is necessary to consider the structure of the facilities and capacity of pump. Considering the conditions of topography, geology, hydrology and difficulty in the pumping operation, 0.1 m^3/s of pump discharge will be the maximum capacity for one set of the system. Furthermore, the maximum number of the pumping system is proposed to be 30. Hence, the limitation of the total amount for water use is expected to be about 3.0 m^3/s using the river pump system.

CHAPTER 4
FIGURES

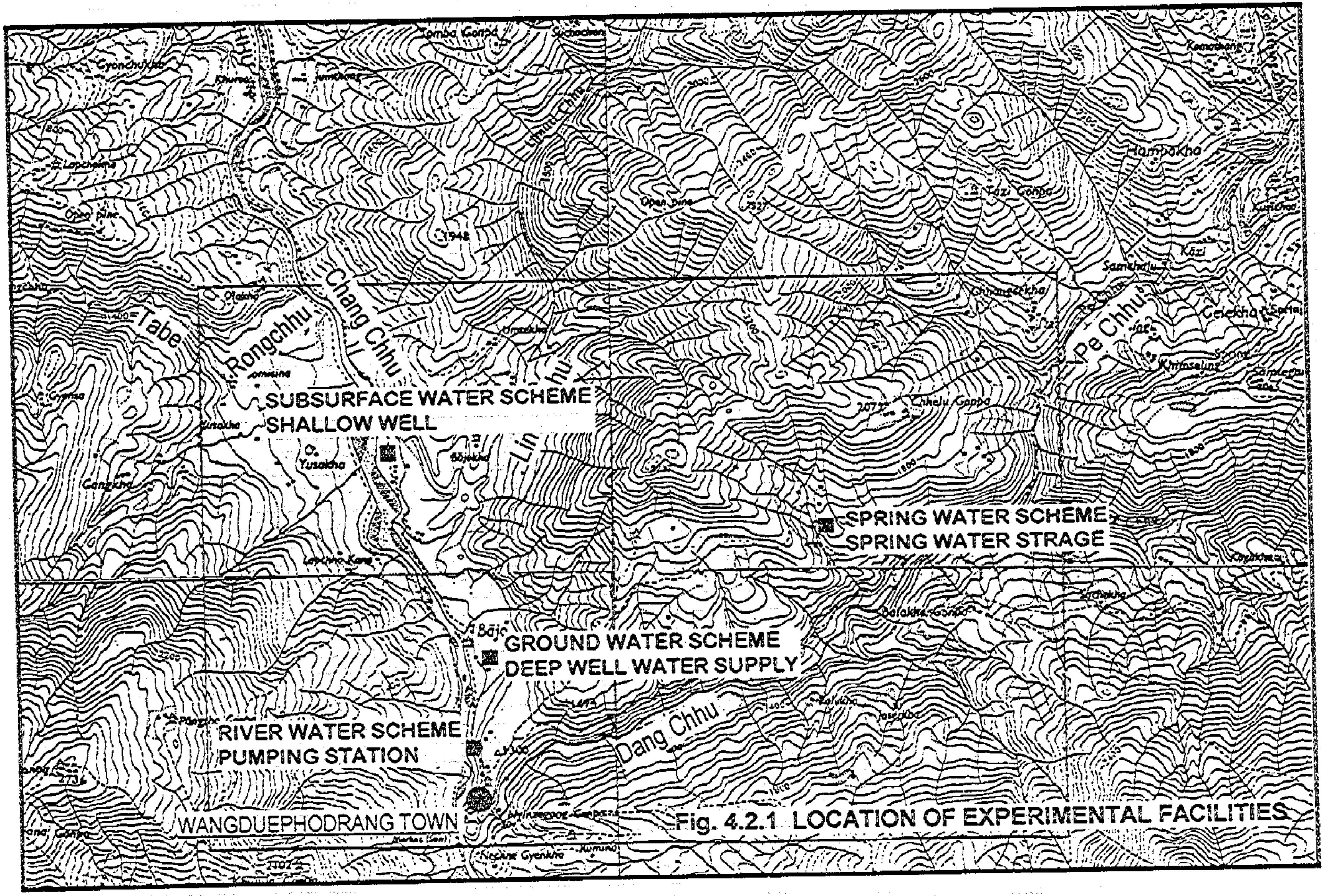


Fig. 4.2.1 LOCATION OF EXPERIMENTAL FACILITIES

SCHEME	Groundwater Scheme	Spring Water Scheme	Subsurface Water Scheme	River Water Scheme
FACILITY	SOLAR POWER SYSTEM	WATER TAP AND STORAGE TANK	SHALLOW WELL	SLIDE TYPE PUMPING SYSTEM
PURPOSE OF MONITORING	To examine technical feasibility, performance and applicability of the solar power system.	To measure the volume of spring water which saved by installing water tap at the outlet of the pipe.	To examine and confirm the technical feasibility, applicability and suitability in applying the shallow well in the area.	- To confirm and examine technical feasibility, applicability of the slide type pumping station in the area including operation and management aspects. - To confirm overall performance of irrigation water management with pumping system.
MONITORING ITEMS	<u>Effects of Solar Power System</u> - Operation hours with solar and electric power systems. - Volume of water lifted up with solar and electric power systems. <u>Other Reference Records</u> - Meteorological records - Maintenance records	<u>Effects of Water Tap</u> - Volume of spring water saved by installing water tap - Purpose of using water	<u>Basic Hydrological Condition of Well</u> - Basic data on hydrological conditions of shallow well (Pumping Tests) <u>Relation between Subsurface and River Water</u> - River and well water levels <u>Other Reference Records</u> - Meteorological records - Maintenance records - Purpose of using water	<u>Performance of Slide Type Pump</u> - Variation of river water level - Position of pump units - Discharge and operation hours of pumping units - Suction and discharge pressure - River water temperature <u>Performance of Floating Suction</u> - Position of suction hoses - Damage and difficulties in positioning hoses <u>Water Management</u> - Water levels in primary and secondary tank - Operation of 2nd. stage pump <u>Other Reference Records</u> - Meteorological records - Operation and maintenance records

Fig. 4.2.2 MONITORING PURPOSES AND ITEMS

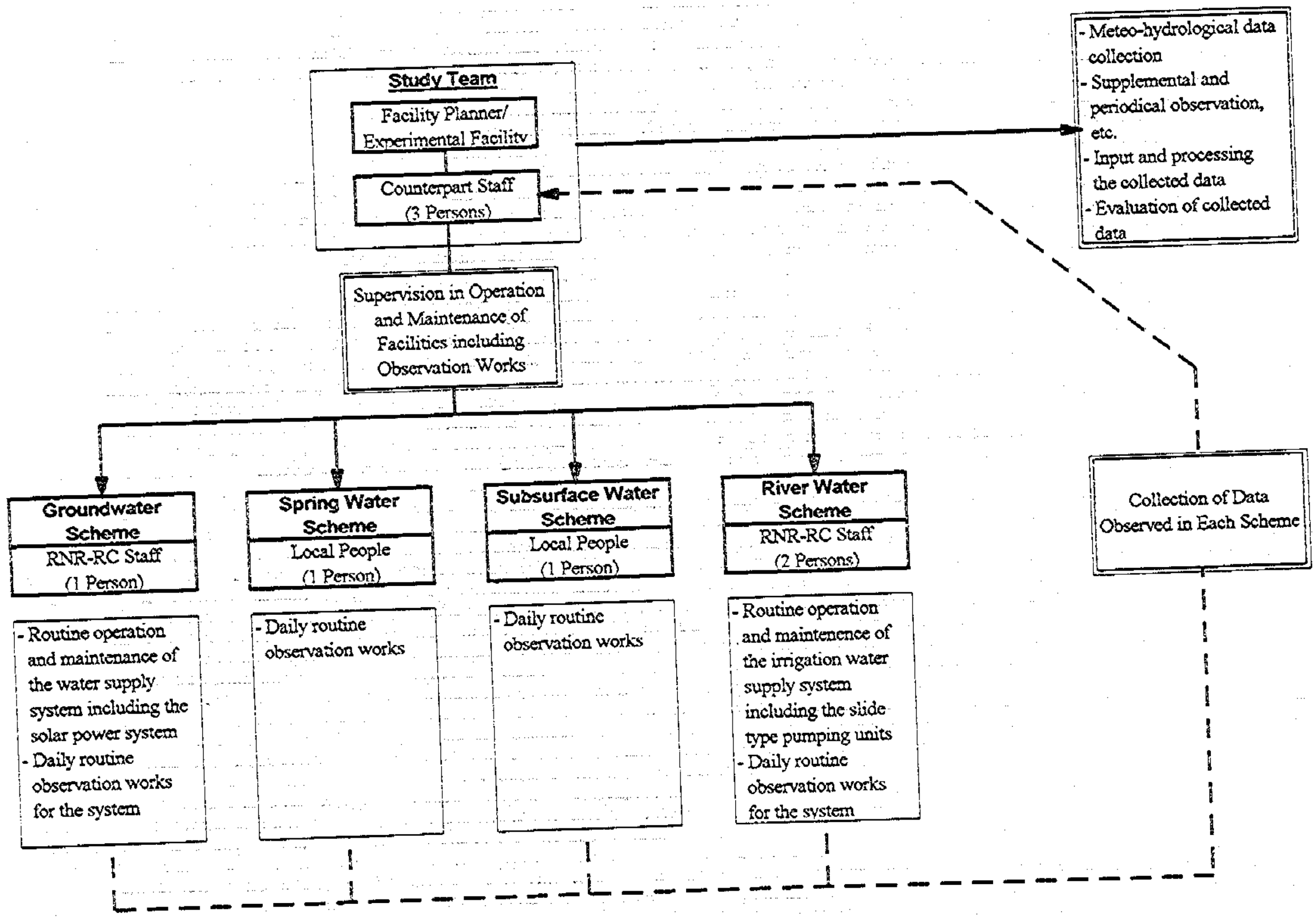


Fig. 4.2.3 MONITORING FORMATION

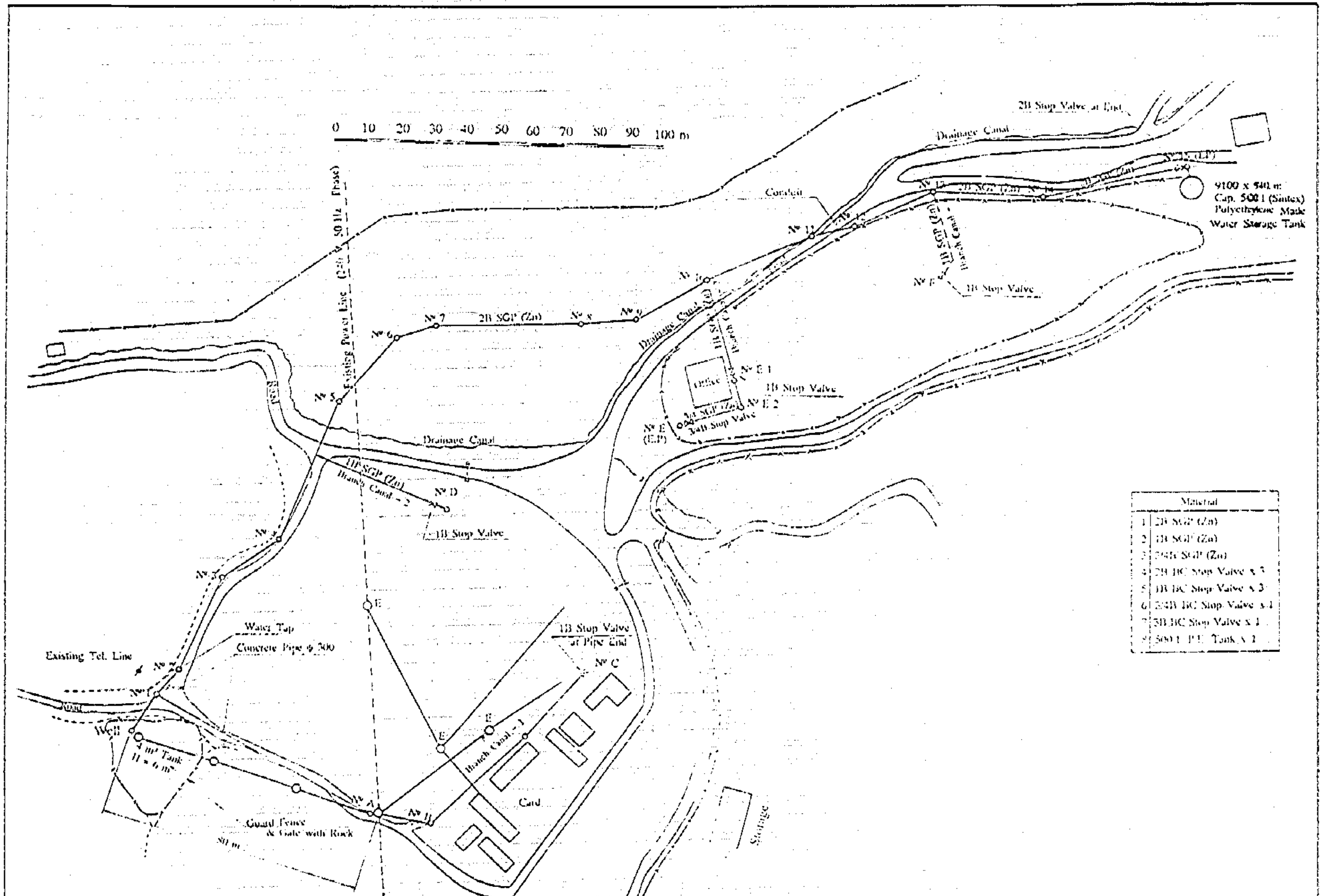


Fig. 4.2.4 GENERAL PLAN AND DISTRIBUTION NETWORK OF WATER SUPPLY FACILITY OF DEEP WELL

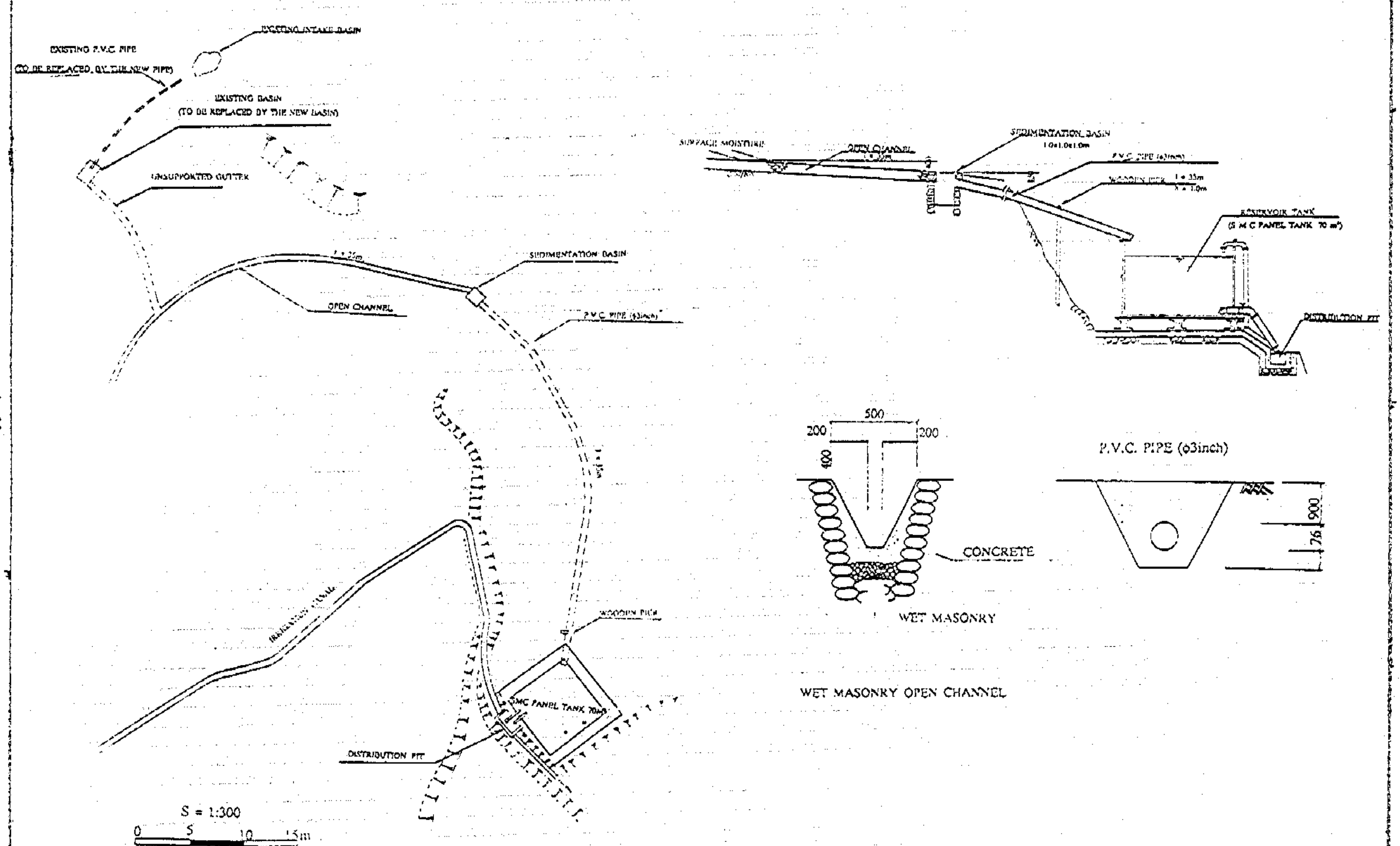


Fig. 4.2.5 GENERAL PLAN OF SPRING WATER STORAGE FACILITY

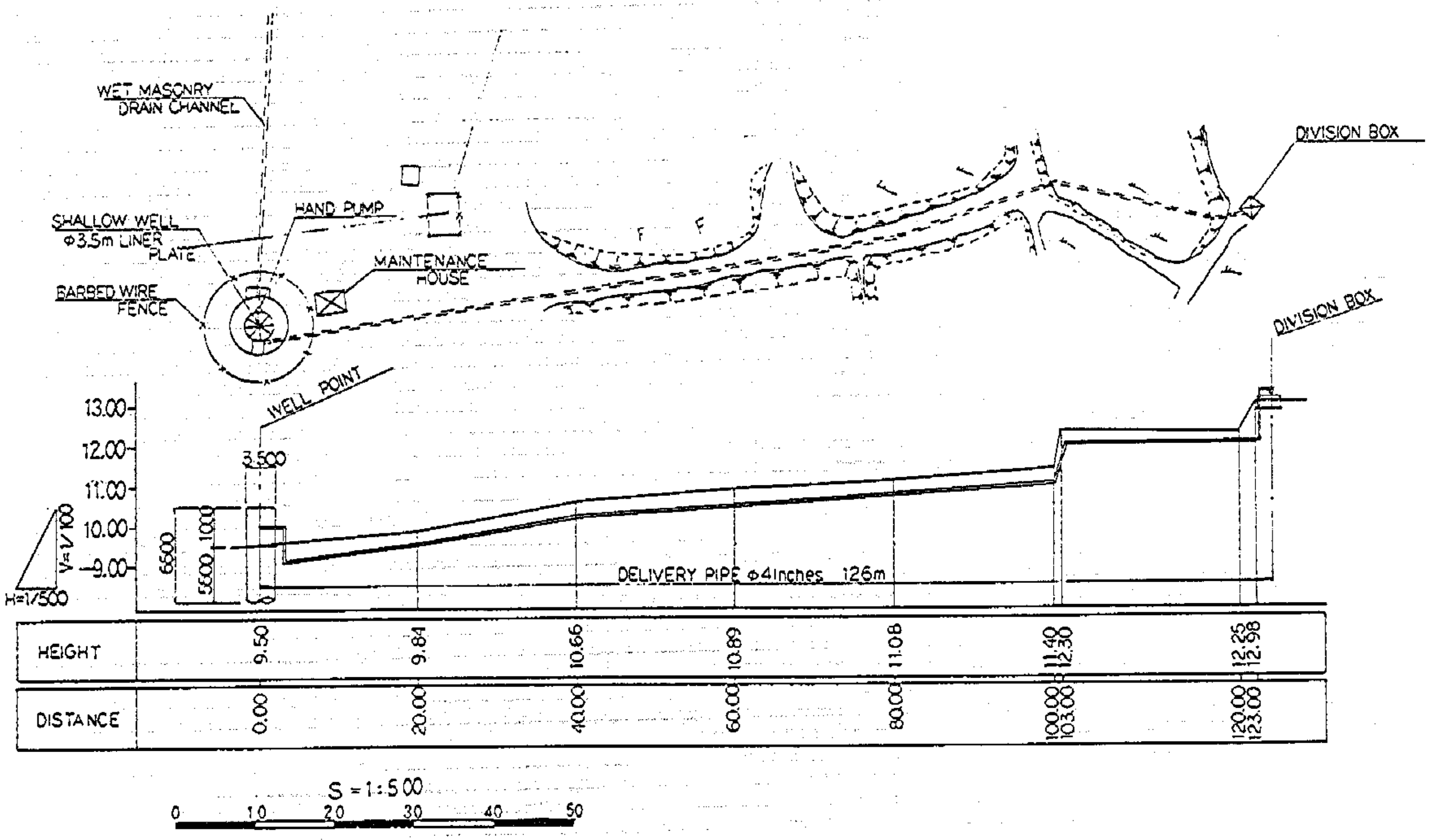


Fig. 4.2.6 GENERAL PLAN OF SHALLOW WELL PUMPING FACILITY

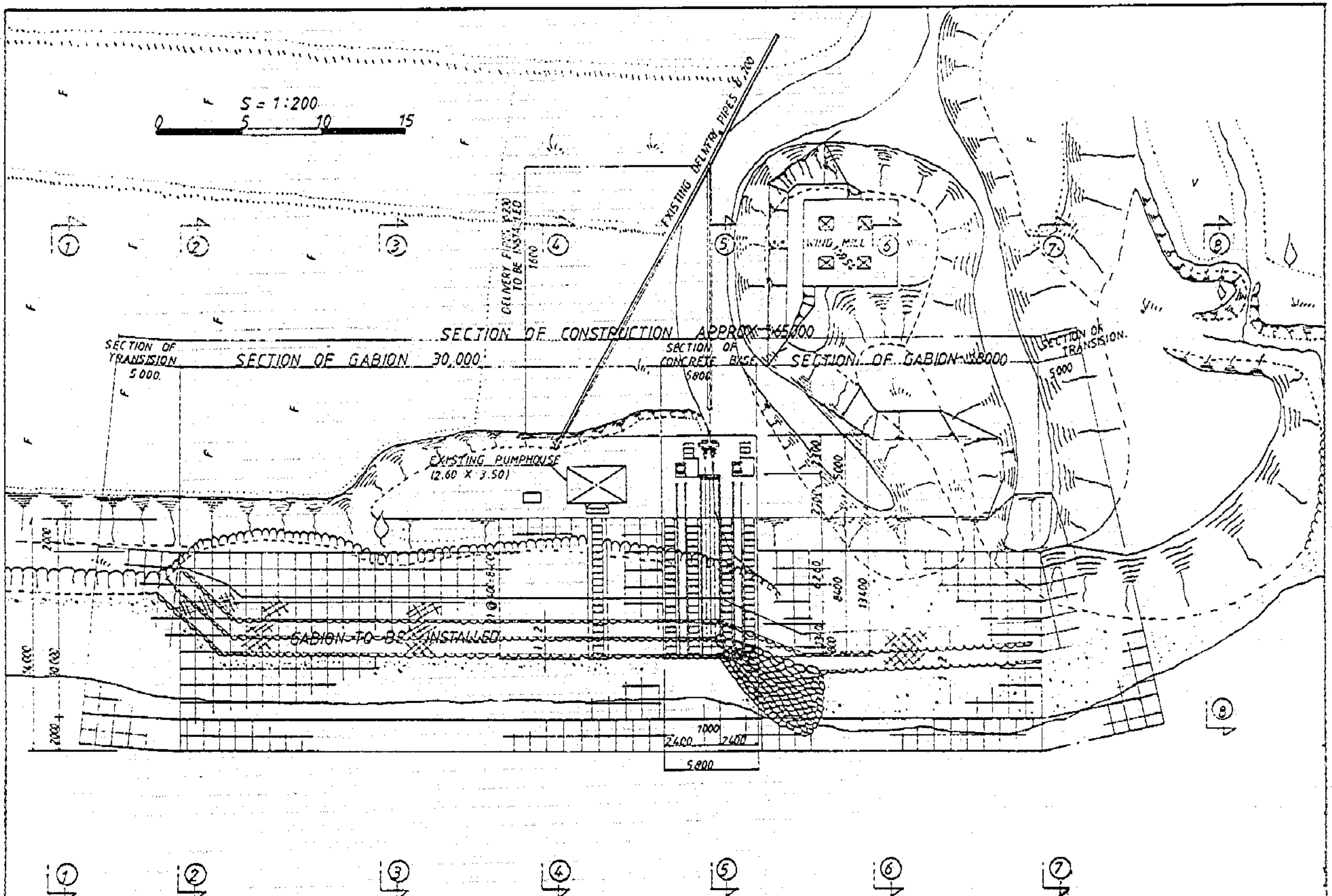


Fig. 4.2.7 GENERAL PLAN OF RIVER PUMPING STATION

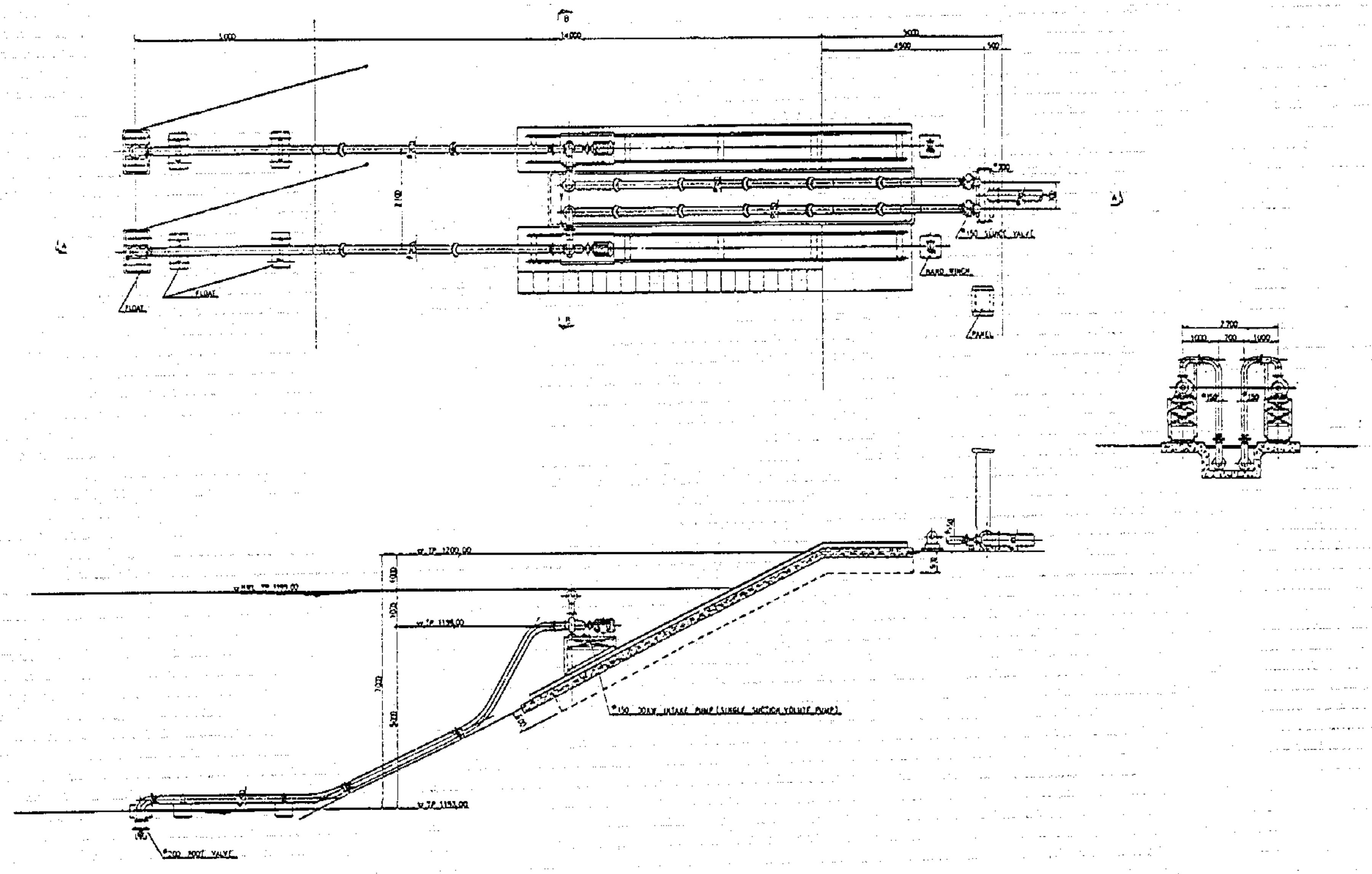


Fig. 4.2.8 LAYOUT PLAN AND PROFILE OF RIVER PUMPING STATION

CHAPTER 5
IRRIGATION WATER MANAGEMENT AND WATER REQUIREMENT

5. Irrigation Water Management and Water Requirement

5.1 Present Condition of Irrigation System

Most of the existing irrigation canals were constructed by the farmers themselves a long time ago, and, the year of construction of such canals is not known. Those are of gravity-flow type intake made of stone masonry and of earth canals carrying water by gravity. Most of these canals are unlined. As presented in Table 5.1.1, there are 22 irrigation canals in and around the Study Area, and the total length is measured as over 100 km and total command area is approximately 1,250 ha. The location of these canals is shown in Fig. 5.1.1. All of the irrigation canals have their source in the tributaries or small streams flowing into the Chang Chhu and the Dang Chhu.

Since 1981, the Small Farms Development and Irrigation Rehabilitation Project (SFDIRP: IFAD - Phase 1) has been implemented by RGOB with assistance of IFAD and 37 irrigation canals have been renovated in the Punakha-Wangdue Valley. The total command area is reported to be about 3,400 ha. In July 1989, the Punakha-Wangdue Valley Development Project (PWVDP: IFAD - Phase 3) was started as a follow up of the above SFDIRP. One of the objectives of the PWVDP is to improve agricultural production through rehabilitation of the existing irrigation canals. The completion of on-going PWVDP is scheduled for June 1996. Under PWVDP, stone masonry canals are constructed partially, mainly for the upper portions of canals where land sliding often occurs.

As described above, some of these canals constructed by local farmers years ago have been rehabilitated, improved and reconstructed by the Dzongkhags of Wangduephodrang and Thimphu under IFAD finance. The participation of IFAD is considered to provide the most extensive assistance in recent years as indicated in Table 5.1.1.

(1) Lobeysa Sub-area

The sub-area is irrigated by Lobeysa Lower and Upper irrigation canals, and the length of these canals are measured to be about eight (8) and seven (7) km, respectively. Irrigated area is about 330 ha. The water source of these canals is the Tabe Rongchhu flowing into the Chang Chhu.

Intakes of these canals are the natural flow type, without water control facilities like gates, etc. Spillways are provided on these canals to drain surplus water to Tabe Rongchhu.

The canals run along valley slope of the Tabe Rongchhu with an approximate length of three (3) km from the intake sites to the command area of Lobeysa sub-area. Soil erosion occurs often due to rainfall and drain runoff from Thimphu-Wangdue road on the valley slope, resulting in damage to the irrigation canals. The Upper Lobeysa canal is currently under renovation with the IFAD project.

(2) Bajo Sub-area

The Bajo canal which is also constructed with the assistance of IFAD is one of the longest canals in the Study area, and its length and command area are about 15 km and 143 ha (including RNRRC area), respectively. The irrigation canal was constructed to provide irrigation water to cultivated areas of the Bajo sub-area as well as to provide domestic water to Wangduephodrang town. The water source of this canal is the Pe Chhu, one of the tributaries of the Dang Chhu. Parallel lines of pipeline have been constructed along the existing road from the Pe Chhu intake site to the water distribution station of the Wangduephodrang town to convey water more effectively.

The Bajo canal runs on the mountain slope for an approximate distance of nine (9) km distance from the Pe Chhu intake site to the water distribution station near Wangduephodrang town. Along this segment of canal, spill over of irrigation water has occurred due to poor water management.

The irrigation water of this sub-area is provided mainly from the Bajo canal, but during the dry season when the conveyed water is not enough to irrigate this area, surplus water of the Limti Chhu is commonly diverted for irrigating this sub-area. However, during the transplanting season, almost all discharge of the Limti Chhu is diverted to paddy fields at the upper part of the river.

(3) Phangyul Sub-area

The Phangyul sub-area extends along the south-eastern side of the mountain ridge running along the Pe Chhu and the Dang Chhu toward Wangduephodrang town. Most of the cultivated lands are developed on the steep slopes forming rice terraces. The most important irrigation canal of this sub-area is the Phangyul canal which has its water source at the Lachu, a tributary of the Komathang Chhu. The length of the Phangyul canal running along the contour line over 2,000 m southwestward is about 16 km. Although a large amount of water is diverted at its intake, the water is not conveyed properly to the canal end located near Wangduephodrang town, because of seepage from the canal and excessive discharge taken from the canal at its upstream portion. The Gemkha canal is also located in this sub-area, but its command area is measured as small as 15 ha only. Water source of this canal is the Uship, also a tributary of Komathang Chhu.

(4) Rubeysa Sub-area

The sub-area extends along the Taka Rongchhu and the left side of the Mochuna. There are five (5) irrigation canals running through the sub-area. The water sources of these canals are the Taka Rongchhu and the Mochuna flowing from the southeastern mountain area. The sub-area suffers from serious irrigation water shortage especially in the downstream portion of the Taka Rongchhu. One of the reasons of water shortage is seepage from the canal at its upstream portion. Most of the canals are unlined, and permeability of soil is observed to be high.

5.2 Water Management, Operation and Maintenance and Water Rights

Generally, water management activities are done by beneficiary farmers. Farmers appoint one or two water guards for inspection of the main canal and intake. Water management for secondary to on-farm canals is done by each farmer or jointly by several farmers related to the operation of the respective canals. From the main canal, small secondary canals (sometimes gullies or natural water courses) run down the slope to the field level. Usually farmers have to divert the irrigation water to the field which is located on the highest terrace, from where water flows to the subsequent lower terraces.

Water is distributed to farmer fields in rotation, and the irrigation interval differs from canal to canal depending on location of field, water availability and farmer's water right. For example, each household in a village receives water on a fixed day at a fixed time, regardless of the area, number and location of the land he owns.

Mostly, canal is cleaned by farmers once a year before transplantation period of paddy. Each household dispatches a person for this canal maintenance work. In the case of repair work for damaged canals, farmers jointly work to carry materials such as stone, sand, log flumes, etc. Results of survey of water management and O/M situation of several canals in the Study area are presented in Table 5.2.1.

Recently, MOA launched the National Irrigation Policy (NIP) for a sustainable approach to irrigation development through the effective participation of the water users. Under this policy, project beneficiaries associate themselves in an organization which is formally constituted as a Water Users Association (WUA). A WUA can be officially established at any time but always begins before implementation of the government-assisted project. NIP was approved officially in August 1992. According to procedure of NIP in PWVDP, several WUAs were formed before the commencement of rehabilitation works of irrigation canals. There are more than 30 WUAs in the Punakha - Wangdue Valley area.

5.3 Present Irrigation Water Requirements

Some information on water requirement is available at RNRRC but the cropping conditions of cultivated land in the Study area are quite different from that of RNRRC. Therefore, the water requirements were estimated in the manner employed in FAO, Irrigation & Drainage Paper No.24 (1977) as described in Appendix H.

The estimation was carried out applying present cropping pattern as shown in Fig. 3.7.1 by each half-month, and the maximum water requirement was found in May second half-month. The amounts of the maximum water

Maximum Water Requirement (May)

(unit: l/sec)

Return Period	Lobeysa	Bajo	Rubeysa	Phangyul
1/2	946	370	190	385
1/5	965	378	195	395
1/10	972	381	197	400
1/20	977	383	199	403
1/5 (Exceedance)	910	356	183	371
1/10 (Exceedance)	887	347	179	362
1/20 (Exceedance)	864	338	175	354

requirement are summarized in the table in the previous page.

As for the future water requirement, as some case studies will be conducted for various conditions considering different cropping patters and water management practices, the future water requirement will vary case by case. Therefore, the most appropriate values will be proposed as discussed in Chapter 8 of this report.

5.4 Problems of Existing Irrigation Scheme

5.4.1 Estimation of Water Balance for 10 Irrigation Schemes

10 irrigation schemes in the sub-area were selected and inventory works were carried out. The present cropping area in each command area is shown in the table for the 10 schemes.

Present Cropping Areas of Existing 10 Schemes

Canal Code	Name of Canal	CP1	CP2	CP3	CP4	CP5	Total
C1	Upper Lobeysa	21	6	0	31	3	61
C2	Lower Lobeysa	105	30	0	150	15	300
C9	Bajo	50	15	0	72	7	143
C10	Phangyul	31	10	0	46	4	91
C15	Gemkha	5	2	0	8	1	15
C18	Nalakha	10	3	0	15	1	29
C19	Rutekha	14	4	0	20	2	40
C20	Maphekha	9	3	0	14	1	27
C21	Naykoyuwa	8	2	0	12	1	24
C22	Rumina	10	3	0	14	1	28

As two (2) schemes in Lobeysa and four (4) schemes in Rubeysa divert the water from same rivers, these 10 schemes are grouped into six (6) groups. The results of inventory are summarized as shown below.

List of Irrigation Scheme in the Sub-Area

Sub-Area	Group	Code	Name of Canal	Canal Length (km)	Command Area (ha)	No. of Benefited Household	Water Source: River	Water Source: Catchment Area (km2)	Water Source: Altitude (m)	Mean Discharge (m3/s)	Estimated Capacity (m3/s)
Lobeysa	A	C1	Upper Lobeysa	7.1	61	117	Tale	119.40	1,400	6.574	0.174
		C2	Lower Lobeysa	8.1	300	123	Rangchhu	119.40	1,380	6.574	0.858
Bajo	B	C9	Bajo	15.0	143	52	Pe Chhu	145.70	1,420	8.022	0.378
Phangyul	C	C10	Phangyul	16.0	91	42	Ladchu	2.21	2,330	0.123	0.240
	D	C15	Gemkha	3.5	15	23	Ushup	0.84	1,750	0.046	0.040
Rubeysa	E	C18	Nalakha	3.9	29	10	Mechum	8.78	1,440	0.183	0.077
	F	C19	Rutekha	2.2	40	60	Takarong	3.03	1,880	0.167	0.106
		C20	Maphekha	2.2	27	41	Chhu	6.23	1,760	0.343	0.071
		C21	Naykoyuwa	1.7	24	18		2.95	1,920	0.162	0.063
		C22	Rumina	1.1	28	35		6.80	1,560	0.374	0.074

Based on the result of hydrological study, the available river discharge were roughly estimated at each intake site as shown below.

Available River Discharge at Intake Site

(Unit : m^3/s)

Group	Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	C1												
	C2	2.081	2.000	1.862	2.585	3.227	6.423	9.963	13.401	10.862	4.853	3.429	2.423
B	C9	2.540	2.410	2.272	3.154	3.938	7.837	12.157	16.357	13.254	5.922	4.184	2.957
C	C10	0.039	0.037	0.035	0.048	0.060	0.120	0.186	0.250	0.202	0.090	0.064	0.045
D	C15	0.015	0.014	0.013	0.018	0.023	0.045	0.070	0.094	0.076	0.034	0.024	0.017
E	C18	0.153	0.147	0.137	0.190	0.237	0.472	0.732	0.985	0.798	0.357	0.252	0.178
F	C19												
	C20												
	C21												
	C22	0.119	0.114	0.106	0.147	0.184	0.366	0.567	0.763	0.619	0.276	0.195	0.138

The water requirement for each canal was estimated based on the water requirement for the sub-area and the result of inventory work. Using these results, the water balance was examined at each intake site as shown in Table 5.4.1.

According to the results presented in Table 5.4.1, three (3) groups namely Groups C, D, F suffer from the water shortage in May which is considered as the season traversing from winter crops to paddy planting and the most important period of transplanting of paddy. The paddy can not be planted usually in whole of paddy fields. The paddy can not be planted in almost half of the farmers' paddy fields according to the interview surveys conducted during the field survey. Furthermore, in Group C (the Phangyul canal), the water shortage occurs for three (3) months from January to March, and hence the production of winter crop in this area might be decreased in this case considering the cropping period of winter crops.

The following table presents the water sufficiency in May, which is derived from the water balance study considering the estimated canal capacity in addition to the above available water resources.

Sufficiency of Water Source and Canal Capacity in May

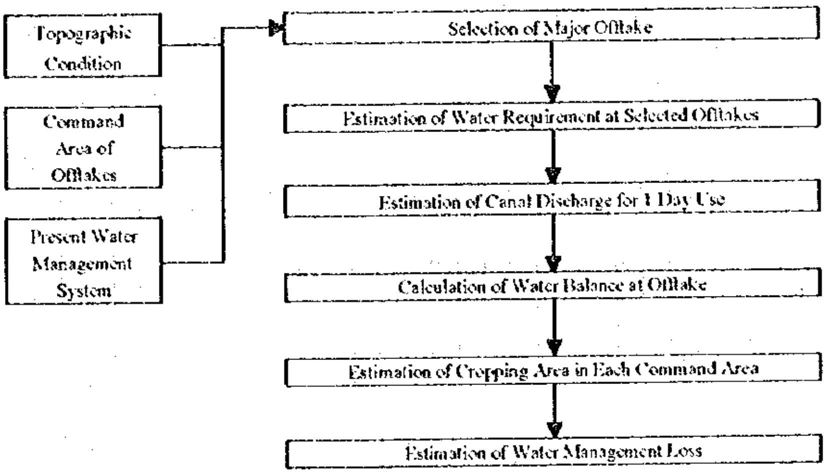
Canal Groupe	Code	Command Area (ha)	Max. Water Requirement (m^3/sec)	Available Water Resources: River Discharge (m^3/sec)	Available Water Resources: Shortage of Water (m^3/sec)	Available Water Resources: Sufficiency at Intake Site (%)	Canal Capacity: Canal Capacity (m^3/sec)	Canal Capacity: Shortage of Water (m^3/sec)	Canal Capacity: Shortage of Capacity (%)	Estimated Cropping Rate (%)
A	C1	61	0.191				0.174	-0.017	-9%	95%
	C2	300	0.942				0.858	-0.084	-9%	96%
	sub-total	361	1133	3.227	-	-	1032	-0.101	-9%	96%
B	C9	143	0.451	3.938	-	-	0.378	-0.073	-16%	90%
C	C10	91	0.256	0.075	-0.181	-71%	0.240	-0.016	-6%	58%
D	C15	15	0.042	0.023	-0.019	-46%	0.040	-0.002	-6%	72%
E	C18	29	0.082	0.237	-	-	0.077	-0.005	-7%	96%
F	C19	40	0.113				0.106	-0.008	-7%	
	C20	27	0.076				0.071	-0.005	-7%	
	C21	24	0.068				0.063	-0.005	-7%	
	C22	28	0.079				0.074	-0.005	-7%	
	sub-total	119	0.337	0.184	-0.153	-45%	0.314	-0.023	-7%	73%

The canal capacity is estimated considering design dimensions and actual conditions of the respective canals such as topography, structure, etc. It is expected that the capacities of all canals are not sufficient; the calculated sufficiency varies within a range of 7% ~ 16% at the maximum water requirement in May.

In estimating the cropping rates the rate of decrease is set at 40 % - 60 % of the water shortage considering the results of field investigation. As a result, the average cropping rate of 86 % is calculated against the total command area, and it is confirmed that there is a basic constraint in the available water resource in six (6) schemes out of 10. This cropping rate may vary depending on the available annual rainfall, and not always shows in the actual situations. However, this is applicable for the Study indicating the irrigation conditions.

5.4.2 Evaluation of Present Water Management System

The present operation system was analyzed and evaluated applying the water balance calculation as shown in Appendix H. The calculation flow of water balance is shown in the figure.



CALCULATION FLOW OF WATER MANAGEMENT

The sufficiency of irrigation water is calculated based on the total water requirement and the amount of available irrigation water at intake site. Based on this sufficiency, the total cropping rate is estimated for the conditions without management loss. The difference between the cropping rate with and without the management loss indicates the degree of management loss. The sample calculation for the C10 canal in the Phangyul sub-area is shown below.

Water Balance at Offtake Point of Phangyul Canal

1) Case: Water Sufficiency 100 %

Group : C		Code : C10		Name of Canal : Phangyul			
Offtake No	Command Area (ha)	Water Requirement (l/sec)	Available Water for 1 day (l/sec)	Water Balance (l/sec)	Water Sufficiency (%)	Estimated Cropping (%)	Estimated Planting Area (ha)
No1	0.36	1.025	1.025	0.000	0.00%	100.00%	0.36
No2	0.93	2.609	2.609	0.000	0.00%	100.00%	0.93
No3	1.32	3.725	3.725	0.000	0.00%	100.00%	1.32
No4	4.12	11.596	27.587	15.991	137.90%	100.00%	4.12
No5	1.02	2.862	27.567	24.705	863.22%	100.00%	1.02
No6	8.72	24.537	27.587	3.050	12.43%	100.00%	8.72
No7	14.66	41.259	27.587	-13.672	-33.14%	80.11%	11.74
No8	20.15	56.717	27.587	-29.130	-51.36%	69.11%	13.94
No9	2.10	5.923	27.587	21.654	365.72%	100.00%	2.10
No10	24.32	68.461	27.587	-40.874	-59.70%	64.15%	15.61
No11	4.12	11.626	27.587	15.959	137.66%	100.00%	4.13
No12	8.99	25.300	27.567	2.267	9.01%	100.00%	8.99
Total	90.82	255.640	255.641	0.000	100.00%	80.36%	72.98

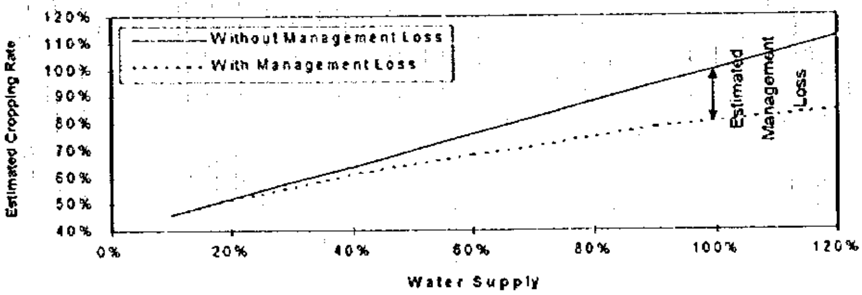
Estimated Cropping Rate without Operation Loss 100.00%
Estimated Cropping Rate with Operation Loss 80.36%
Estimated Operation Loss 19.64%

2) Case: Water Sufficiency 29.4 %

Group : C		Code : C10		Name of Canal : Phangyul			
Offtake No	Command Area (ha)	Water Requirement (l/sec)	Available Water for 1 day (l/sec)	Water Balance (l/sec)	Water Sufficiency (%)	Estimated Cropping (%)	Estimated Planting Area (ha)
No1	0.36	1.025	1.025	0.000	0.00%	100.00%	0.36
No2	0.93	2.609	2.609	0.000	0.00%	100.00%	0.93
No3	1.32	3.719	3.719	0.000	0.00%	100.00%	1.32
No4	4.12	11.596	7.516	-4.081	-35.19%	78.89%	3.25
No5	1.02	2.882	7.516	4.634	160.78%	100.00%	1.02
No6	8.74	24.557	7.516	-17.021	-69.37%	58.38%	5.09
No7	14.56	41.259	7.516	-33.743	-81.78%	50.97%	7.47
No8	20.15	56.717	7.516	-49.201	-86.75%	47.95%	9.66
No9	2.10	5.923	7.516	1.592	26.88%	100.00%	2.10
No10	24.32	68.461	7.516	-60.945	-89.02%	46.59%	11.33
No11	4.12	11.608	7.516	-4.092	-35.25%	78.83%	3.25
No12	8.99	25.300	7.516	-17.784	-70.29%	57.82%	5.20
Total	90.82	255.641	75.000	-180.641	29.34%	56.13%	50.79

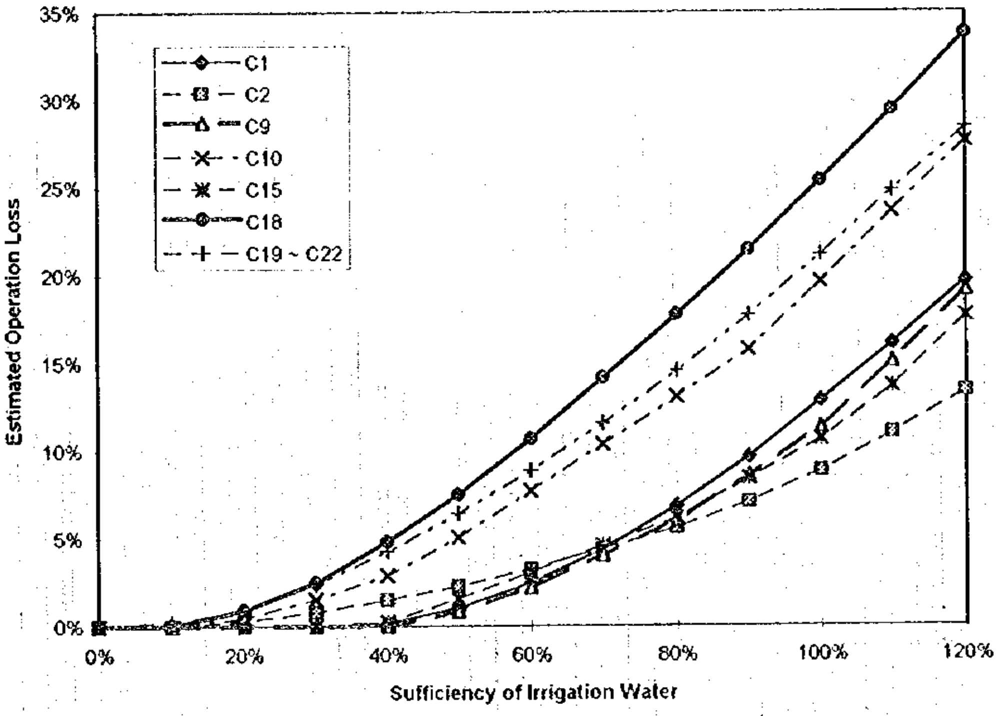
Estimated Cropping Rate without Operation Loss 57.69%
Estimated Cropping Rate with Operation Loss 56.13%
Estimated Operation Loss 1.46%

About 20 % of operation loss is calculated for the case that the water sufficiency is 100 %. In case of about 30 % of water sufficiency, about 1.5 % of operation loss is calculated. This tendency is illustrated below.



CROPPING RATE BY SUFFICIENCY OF WATER

Based on the results of these calculations, the water management loss for the 10 schemes is estimated, and the results are plotted as shown below.



OPERATION LOSS ESTIMATED FOR EACH IRRIGATION CANAL

10 % ~ 25 % (14 % for the total area) of water management loss is expected even if 100 % of irrigation water is supplied. In the present condition, as there is a constraint in irrigation supply coursed by shortage of water source or canal capacity, 1 % - 23 % (7 % for the total area) of water management loss is expected. The result are summarized below.

Summary of Estimated Water Management Loss

Canal Grope		A		B	C	D	E	F
Code No.		C1	C2	C9	C10	C15	C18	C19-C22
Command Area (ha)		61	300	143	91	15	29	119
Max. Water Requirement (May m3/s)		0.191	0.942	0.451	0.256	0.042	0.082	0.337
Case 1	Amount of Available Water at Intake Site	0.191	0.942	0.451	0.256	0.042	0.082	0.337
	Sufficiency of Irrigation Water	100%	100%	100%	100%	100%	100%	100%
	Estimated Cropping Rate without Management Loss	100%	100%	100%	100%	100%	100%	100%
	Estimated Cropping Rate with Management Loss	87%	91%	89%	80%	89%	75%	79%
	Estimated Management Loss	13%	9%	11%	20%	11%	25%	21%
	Estimated Cropping Area (ha)	53.2	273.5	126.8	73.1	13.4	21.7	93.8
Case 2	Amount of Available Water at Intake Site	0.175	0.858	0.378	0.075	0.023	0.077	0.184
	Sufficiency of Irrigation Water	91%	91%	84%	29%	55%	93%	55%
	Estimated Cropping Rate without Management Loss	95%	96%	90%	58%	72%	96%	73%
	Estimated Cropping Rate with Management Loss	85%	89%	83%	56%	70%	73%	65%
	Estimated Management Loss	10%	7%	7%	1%	2%	23%	8%
	Estimated Cropping Area (ha)	51.7	267.6	119.2	51.1	10.5	21.2	77.8

CHAPTER 5
TABLES

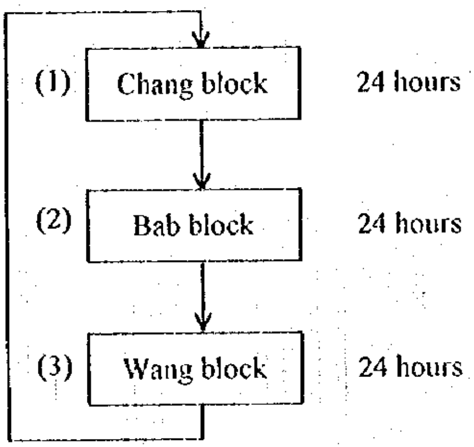
Table 5.1.1 List of Irrigation Canals in and around the Study Area

Code	Name of Canal	Canal Length (Km)	Command Area (ha)	Number of Benefited Household	Government Assistance		Water Source
					IFAD-I	IFAD-III	
C 1	Upper Lobeysa	7.1	61	117	○	○	Tabe Rongchhu
C 2	Lower Lobeysa	8.1	300	123	○		Tabe Rongchhu
C 3	Rinchengang	9.0	65	38	○		Nabe Rongchhu
C 4	Omte	3.5	21	25			Limti Chhu
C 5	Tata	2.0	22	24			Limti Chhu
C 6	Sichu	3.8	52	24			Limti Chhu
C 7	Gigu	1.6	41	34			Limti Chhu
C 8	Towgee	3.5	26	43			Limti Chhu
C 9	Bajo	15.0	143	52		○	Pe Chhu
C10	Phangyul	16.0	91	42	○		Lachu
C11	Komathang	4.0	7	40		●	Komathang Chhu
C12	Chungsekha	6.9	200	50	○		Komathang Chhu
C13	Lower kashi	2.4	20	37		○	Komathang Chhu
C14	Jagatokha	4.3	16	39		○	Komathang Chhu
C15	Gemkha	3.5	15	23			Uship
C16	Balakha	4.0	40	50	○	○	Mochuna
C17	Themakha	3.1	40	35	○	○	Mochuna
C18	Nalakha	3.9	29	10		○	Mochuna
C19	Rutekha	2.2	40	60			Takarong Chhu
C20	Maphekha	2.2	27	44		●	Takarong Chhu
C21	Naykoyuwa	1.7	24	18			Takarong Chhu
C22	Rumina	1.1	28	35			Takarong Chhu

Note: ● - Planned to renovate from fiscal year 1994/95.

Table 5.2.1 Water Management and O/M of Canals (sheet 1/4)

Name of Canal	**Upper Lobeysa**
Water Users Association	Exists
Number of water guards	1 person
Payment to water guard	5 N/0.1ha or 1.5 kg/0.1 ha
Canal maintenance	Major maintenance work is done one time per year before paddy plantation
Water allocation	There are 3 major irrigation blocks (villages), rotation of one day/night (24 hours) for each irrigation block



Name of Canal	**Lower Lobeysa**
Water Users Association	Does not exist (planned to be formed)
Number of water guards	4 person (There are 4 offtake)
Payment to water guard	no payment (water guard is changes yearly)
Canal maintenance	Major maintenance work is done one time per year before paddy plantation
Water allocation	rotation of one day/night (24 hours) for each irrigation block

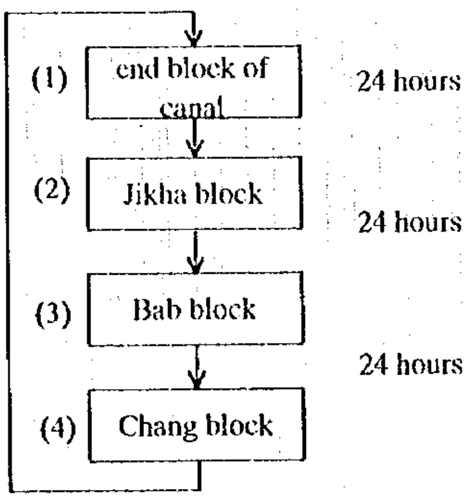
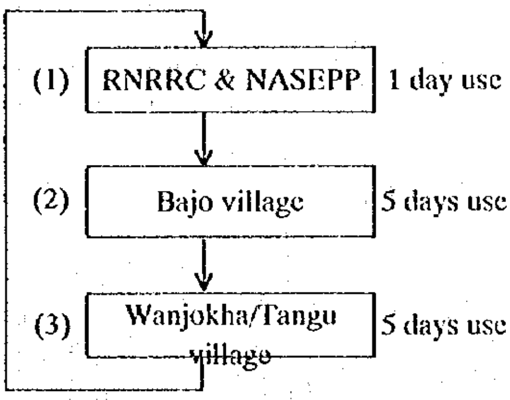
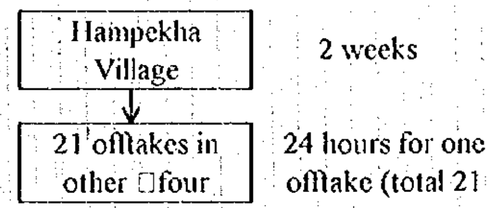


Table 5.2.1 Water Management and O/M of Canals (sheet 2/4)

Name of Canal	Bajo
Water Users Association	Does not exist
Number of water guards	2 persons (1person each from Bajo and Wangjokha/Tangu villages)
Payment to water guard	20 ~25 kg/ha of rice
Canal maintenance	Major maintenance work is done one time per year before paddy plantation
Water allocation	one day/night (24 hours) for 1 inlet or 1 acre of rotation



Name of Canal	**Phangyul**
Water Users Association	formed in 1993
Number of water guards	6 persons (1 water guard leader and 1 person each from Phangyul, Kumchi, Gemkha, Chungsekha, Hampekha
Payment to water guard	no payment
Canal maintenance	2 times per year (before and after the paddy cultivation)
Water allocation	A. Transplanting period



B. after transplanting

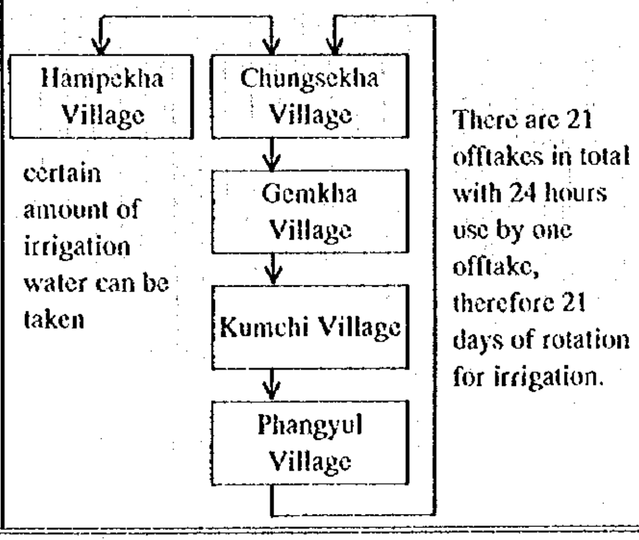


Table 5.2.1 Water Management and O/M of Canals (sheet 3/4)

Name of Canal	**Gemkha**
Water Users Association	Does not exist
Number of water guards	1 person
Payment to water guard	no payment (water guard not responsible for maintenance wo
Canal maintenance	2 times per year (before and after the paddy cultivation)
Water allocation	24 hours per farmer household: rotation on 26 day interval. (according to interview survey, there are 26 benefited households under the Genkha irrigation canal scheme)

Name of Canal	**Nalakha**
Water Users Association	Does not exist
Number of water guards	water guard does not assigned
Payment to water guard	no payment (one year rotation among beneficiaries)
Canal maintenance	---
Water allocation	---

Name of Canal	**Rutekha**
Water Users Association	Does not exist
Number of water guards	water guard does not assigned
Payment to water guard	no payment
Canal maintenance	2 times per year (before and after the paddy cultivation)
Water allocation	rotation --- 24 hours for 2 households (total households : 70)

Name of Canal	**Maphekha**
Water Users Association	Does not exist
Number of water guards	one person
Payment to water guard	no payment
Canal maintenance	2 times per year
Water allocation	rotation --- 24 hours for 2 households (total households : 52)

Table 5.2.1 Water Management and O/M of Canals (sheet 4/4)

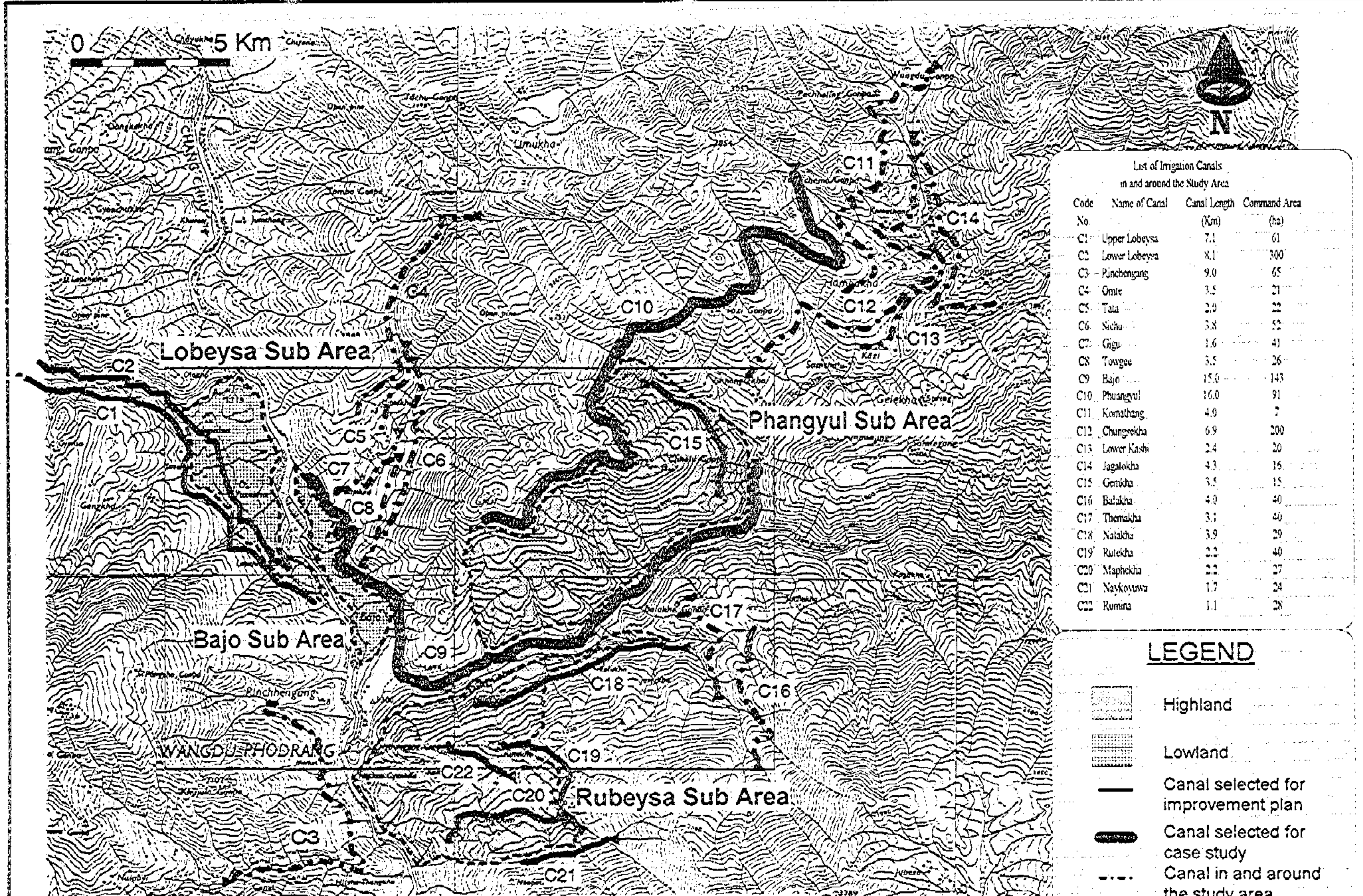
Name of Canal	**Rumina**
Water Users Association	Does not exist
Number of water guards	water guard is turnwise during paddy plantation period by benefited households
Payment to water guard	no payment
Canal maintenance	2 times per year
Water allocation	rotation of 24 hours per household (total benefited households : 35)

Table 5.4.1 Irrigation Water Balance at Intake Site

(unit : m³/s)

Group	Code		Name of Canal				Total Command Area (ha)				Name of River				Catchment Area (km²)									
A	C1,C2		Upper Lobeysa, Lower Lobeysa				361				Taberong Chhu				119.4									
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Available River Discharge	2.081	2.081	2.000	2.000	1.862	1.862	2.585	2.585	3.227	3.227	6.423	6.423	9.963	9.963	13.404	13.404	10.862	10.862	4.853	4.853	3.429	3.429	2.423	2.423
Water Requirement	0.165	0.167	0.243	0.237	0.281	0.206	0.132	0.055	0.000	1.133	0.995	0.710	0.616	0.304	0.326	0.302	0.350	0.313	0.108	0.000	0.071	0.117	0.145	0.166
Shortage of Water																								
Insufficiency																								
Group	Code		Name of Canal				Total Command Area (ha)				Name of River				Catchment Area (km²)									
B	C9		Bajo				143				Pe Chhu				145.7									
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Available River Discharge	2.540	2.540	2.440	2.440	2.272	2.272	3.154	3.154	3.938	3.938	7.837	7.837	12.157	12.157	16.357	16.357	13.254	13.254	5.922	5.922	4.184	4.184	2.957	2.957
Water Requirement	0.065	0.066	0.098	0.095	0.111	0.082	0.054	0.023	0.000	0.451	0.398	0.286	0.251	0.127	0.139	0.129	0.144	0.129	0.042	0.000	0.028	0.046	0.057	0.066
Shortage of Water																								
Insufficiency																								
Group	Code		Name of Canal				Total Command Area (ha)				Name of River				Catchment Area (km²)									
C	C10		Phangyul				91				Lachhu				2.23									
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Available River Discharge	0.039	0.039	0.037	0.037	0.035	0.035	0.048	0.048	0.060	0.060	0.120	0.120	0.186	0.186	0.250	0.250	0.202	0.202	0.090	0.090	0.064	0.064	0.045	0.045
Water Requirement	0.043	0.043	0.050	0.048	0.067	0.049	0.024	0.005	0.000	0.256	0.216	0.148	0.127	0.052	0.048	0.043	0.056	0.047	0.028	0.000	0.019	0.030	0.037	0.042
Shortage of Water	-0.004	-0.004	-0.012	-0.011	-0.033	-0.014				-0.196	-0.097	-0.029												
Insufficiency	-9.0%	-10.2%	-24.9%	-22.4%	-48.5%	-29.1%				-76.5%	-44.7%	-19.3%												
Group	Code		Name of Canal				Total Command Area (ha)				Name of River				Catchment Area (km²)									
D	C15		Gemkha				15				Uship				0.84									
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Available River Discharge	0.015	0.015	0.014	0.014	0.013	0.013	0.018	0.018	0.023	0.023	0.056	0.056	0.116	0.116	0.187	0.187	0.152	0.152	0.042	0.042	0.024	0.024	0.017	0.017
Water Requirement	0.007	0.007	0.008	0.008	0.011	0.008	0.004	0.001	0.000	0.042	0.036	0.024	0.021	0.009	0.008	0.007	0.009	0.008	0.005	0.000	0.003	0.005	0.006	0.007
Shortage of Water										-0.020														
Insufficiency										-46.6%														
Group	Code		Name of Canal				Total Command Area (ha)				Name of River				Catchment Area (km²)									
E	C18		Nalakha				29				Mochuna				8.78									
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Available River Discharge	0.153	0.153	0.147	0.147	0.137	0.137	0.190	0.190	0.237	0.237	0.472	0.472	0.732	0.732	0.985	0.985	0.798	0.798	0.357	0.357	0.252	0.252	0.178	0.178
Water Requirement	0.014	0.014	0.017	0.016	0.022	0.016	0.008	0.002	0.000	0.082	0.070	0.048	0.041	0.017	0.016	0.014	0.020	0.017	0.009	0.000	0.006	0.010	0.012	0.014
Shortage of Water																								
Insufficiency																								
Group	Code		Name of Canal				Total Command Area (ha)				Name of River				Catchment Area (km²)									
F	C19~22		Ruteka, Mapheka, Naykoyuka, Rumina				119				Takarong Chhu				6.8									
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Available River Discharge	0.119	0.119	0.114	0.114	0.106	0.106	0.147	0.147	0.184	0.184	0.366	0.366	0.567	0.567	0.763	0.763	0.619	0.619	0.276	0.276	0.195	0.195	0.138	0.138
Water Requirement	0.056	0.057	0.069	0.067	0.090	0.066	0.035	0.010	0.000	0.337	0.286	0.198	0.168	0.072	0.066	0.059	0.080	0.069	0.036	0.000	0.024	0.040	0.049	0.056
Shortage of Water										-0.153														
Insufficiency										-45.4%														

CHAPTER 5
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	Jagalokha	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.5.1.1 Location of Irrigation Schemes in and around the Study Area.

CHAPTER 6
URBAN AND RURAL WATER SUPPLY DEMAND

6. Urban and Rural Water Supply Demand

6.1 Urban Water Supply for Wangduephodrang Town Area

6.1.1 Present Water Consumption

The variation of water level was observed at the distribution tank, to measure the actual water consumption. As a result about 780 m^3/day of treated water is distributed to the town area by the distribution station with the maximum and minimum flow rates of 110 m^3/hr and 53 m^3/hr. The water consumption per capita is calculated to be about 125 l/day considering that the present population is 6,035 and day visitors also use some amount of water.

The supplied water volume is quite different from place to place depending on the topographic and hydraulic conditions of each location. The field survey on the actual water consumption was carried out in some selected areas in the Wangduephodrang town. The daily water consumption per capita is consequently estimated to be 75 l/day under the present life style as shown in the table. The physical loss is calculated to be about 50 l/day per capita, deducting the above consumption per capita of 75 l/day from the observed consumption per capita of about 125 l/day.

Present Water Consumption per Capita

Description	Consumption
Cloth washing (Laundry)	30 l/c/d
Latrine	5 l/c/d
Bathing	30 l/c/d
Cooking	10 l/c/d
Total	75 l/c/d

6.1.2 Population Projection and Future Water Demand

(1) Present Population Served and Service Area

The present water supply system covers the whole town area of about 110 ha, and all of the population therein is considered to be served by the present system with an intermittent operation. The field survey was conducted during the field survey period to roughly grasp the actual population in these areas, and consequently the present population was estimated at 8,355 for 1995 including the day time visitors of 2,320 as summarized below.

Summary of Surveyed Population in Wangduephodrang Town Area

Category	Population in 1995	
	Residents	Day Visitors
Township Area	1,820	0
Commercial and Shopping Area	520	400
Monk Body	65	0
Administrative Organization	60	150
RBA Complex and Outer Quarters	3,140	370
RBA Hospital	175	200
Primary and Junior High School	30	1,200
RNRRC Office	225	0
Total	6,035	2,320

Construction of a junior high school is going on in the north to the existing AMC yard in the Bajo area, and its completion is scheduled for 1997. The present junior high school is planned to be transferred to the new school when its construction is completed.

(2) Wangduephodrang Town Planning

According to PWD of MOC, the expansion of the present township is considered with some alternatives at present, but any final decision has not yet been made so far due to the limited land resources in the surrounding areas of the township. There are two (2) alternative plans being considered as shown in Fig. 6.1.1, and both plans aim mainly to transfer the existing shopping and commercial areas located at the center of the township to the other areas by:

- newly expanding the town area to include the experimental farm yards of RNRRC for the further development, or
- developing the present residential areas extending on the rather steep slope lands west to the town center along the Chang Chhu.

In planning the future water supply system, it is proposed to adopt the former plan, since it seems to be more possible to reserve such lands for development in the present township than out of it considering that the present experimental farm yards in RNRRC are being utilized to the full extent and there is not any alternative sites for relocation at present.

(3) Future Population Projection

The town development will be made within the present town area according to their town plan, and then no expansion is necessary to be considered. However, some extent of development such as construction of residential houses, etc. is expected to be made in the lands of existing AMC and DSC yards along the Chang Chhu towards the new school site, because such areas are considered to become high potential areas in development when the development is realized in the future based on the said town plan. The service area is, therefore, proposed to be expanded so as to include such areas which are located north to the present township along the Chang Chhu. The expected population increase in such areas to be newly included in the future service area is summarized in the following table.

Projected Population in the Expanded Service Area

Category	2002		2007	
	Residents	Day Visitors	Residents	Day Visitors
Junior High School in Bajothang	10	220	165	435
Agricultural Machinery Center (AMC)	0	7	0	7
Druk Seed Corporation (DSC)	37	6	37	6
Total	47	233	202	448

The future population increase projected for the target year of 2002 and 2007 is set as shown in the table. Since the high growth rate is believed to continue in the future, rather high value, two (2) % per year, is applied for projecting the population in 2002 and 2007 considering the Wangdue-phodrang Dzongkhag's expectation.

Projected Population in Wangduephodrang Town Area

Categories	1995	2002	2007
1. Present Service Area			
Resident	6,035	6,932	7,654
Growth Rate (%)	-	(2.00)	(2.00)
Day Visitors (38%)	2,293	2,634	2,908
Sub-total	8,328	9,567	10,562
2. Extended Service Area			
Resident	0	47	202
Day Visitors	0	233	448
Sub-total	0	280	650
3. Total Population			
Resident	6,035	6,979	7,856
Day Visitors	2,293	2,867	3,356
Total	8,328	9,847	11,212

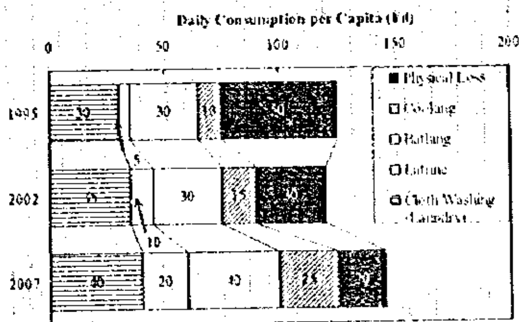
The number of day visitors shares 38 % of the resident population, and the total population is projected at 9,847 (consisting of 6,979 residents and 2,293 day visitors) and 11,212 (consisting of 7,856 residents and 3,356 day visitors) for 2002 and 2007, respectively including those in the present and the future extended service areas. This projected population increase is illustrated in Fig. 6.1.2.

Present and Future Water Consumption per Capita

Description	Present 1995	Future 2002	Future 2007
Cloth Washing (Laundry)	30	35	40
Latrine	5	10	20
Bathing	30	30	40
Cooking	10	15	25
Consumptive Demand	75	90	125
Physical Loss (% to Total Demand)	50 (40)	30 (25)	20 (14)
Total Water Demand	125	120	145

(4) Future Water Demand

The present water consumption per capita is measured to be 125 l/day, which consists of the net consumption of 75 l/day and the physical loss of 50 l/day (40 % of the total demand). Based on this measured value, the future demand is estimated.



PRESENT AND FUTURE WATER CONSUMPTION PER CAPITA

As a result, the consumptive demand per capita is increased from present 75 l/day to 125 l/day in 2007. The total demand per capita will be once decreased from present 125 l/day to 120 l/day in 2002 and will be increased to 145 l/day in 2007 as shown in the table and figure.

Based on the above discussion on the future population and the future water demand per capita, the total water demand for the whole of the served area is calculated. The average daily demand and the maximum daily demand are calculated. The average daily demand is calculated by multiplying the estimated water demand per capita by the served population, and the 25 % - increased value of the average demand is taken for the maximum daily demand. The estimated daily water demands are presented in the table, and are illustrated in Fig. 6.1.3.

Estimated Water Demand

Year	Average Daily Demand (m^3/day)	Max. Daily Demand (m^3/day)
1995	812	1,015
2002	906	1,133
2007	1,236	1,546

6.1.3 Block-wise Population and Water Demand

The service area of the water supply system is divided into six (6) blocks as shown in Fig. 6.1.4. The block-wise population is calculated based on the results of the population survey which was conducted during the field survey period, as shown in the table.

Block-wise Population in the Wangduephodrang Town Area

Year	Blocks 1	2	3	4	5	6	Total
1995	2,935	1,555	950	2,743	145	-	8,328
2002	3,372	1,786	1,618	1,926	166	978	9,847
2007	3,723	1,972	2,368	1,545	183	1,421	11,212

The average and maximum daily demands for each divided block are also calculated taking proportional values of the above calculated block-wise population as shown in the table.

Block-wise Water Demand for the Wangduephodrang Town Area (m^3/day)

Year	Blocks 1	2	3	4	5	6	Total
Average Daily Demand							
1995	286	152	93	267	14	-	812
2002	310	164	149	177	15	90	906
2007	411	217	261	170	20	157	1,236
Maximum Daily Demand							
1995	358	189	116	334	18	-	1,015
2002	388	206	186	222	19	113	1,133
2007	513	272	326	213	25	196	1,546

6.2 Water Supply for Rural Areas

6.2.1 Present Water Consumption

Some field surveys were conducted to grasp the actual water consumption in the rural areas. As shown in the table, the total consumption per capita is observed to be 45 l/day.

Surveyed Water Consumption in Rural Areas

Description	Consumption
Cloth washing (Laundry)	20 l/c/d
Latrine	5 l/c/d
Bathing	10 l/c/d
Cooking	10 l/c/d
Total	45 l/c/d

According to the UNICEF's guideline, the water supply system to be constructed in rural areas should be designed based on the water demand per capita of 67 l/day, which is obtained multiplying the consumption of 45 l/day with 1.5 for the further increase of population. This increase is translated to the annual

Population Increase in Rural Areas

Present Population (1995)	2002	2007
1.0	1.26	1.50

← Annual Growth Rate: 3.4 % →

population increase of about 3.4 % as shown in the above table.

6.2.2 Population and Served Population

As mentioned in the previous chapter, the present population and those served by the present water supply schemes are summarized in the table.

Population and Population Served in the Study Area

Sub-areas	Population	Population Served	Service Ratio (%)
Lobeysa	3,086	2,729	88
Bajo	983	353	36
Phangyul	1,159	414	36
Rubeysa	1,456	1,006	69
Total	6,684	4,502	67

The population of the Study area is 6,684, and 4,502, equivalent to 67 % of the total population are served by the present water supply schemes. The rest of the population of 2,182, equivalent to 33 % are left without any supply system, and they have to take their domestic water from rivers, streams or irrigation canals near their houses facing the risks to be bacteriologically infected.

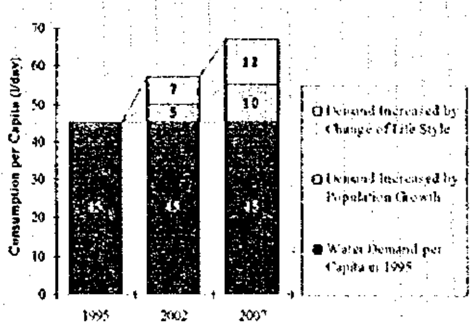
According to the Dzongkhag administration, the population growth rate in rural areas have gradually increased for these ten (10) years in all villages, and it is considered that the population in these rural villages looks like reaching the saturation in the near future because of the limited land resources available and the poor possibility to maintain self-sufficient economy. However, the rural population is considered to increase for the further 10 years at least. Therefore, in this study, it is proposed to apply two (2) % of annual increase, a rather conservative value of increase, for estimating the future population. The projected population in 2002 and 2007 is summarized for each sub-area as shown in the table.

Projected Future Population in the Study Area

Sub-areas	Population		
	1995	2002	2007
Lobeysa	3,086	3,545	3,914
Bajo	983	1,129	1,247
Phangyul	1,159	1,331	1,470
Rubeysa	1,456	1,672	1,847
Total	6,684	7,677	8,478

6.2.3 Water Demand

The present water consumption per capita as measured through the field surveys is 45 l/day as described in the previous section, and this consumption meets that recommended in the UNICEF's guideline. According to the UNICEF's guideline, it is further recommended to apply the 50 % - increased value for estimating the future water consumption per capita. The increased value is calculated to be 67 l/day. In case that the rural population increases with the growth rate of two (2) %, it means that the 45 l/day of consumption per capita would be increased to



INCREASE OF CONSUMPTION PERCAPITA

57 l/day (45 l/day x 1.02^{12}) against the same present population. Therefore, if the value of 67 l/day is applied as recommended by UNICEF, the balance of 10 l/day (67 l/day - 57 l/day) is considered as the value increased due to leveling up of villagers' living standards. This value is equivalent to about 22 % of the present consumption per capita, and is considered quite reasonable taking into account of their present life styles. It is, therefore, proposed to apply the same values as the UNICEF's guideline for planning rural water supply systems in the Study area as shown in the table.

Present and Future Water Consumption per Capita

(l/day)

Present	Future	
1995	2002	2007
45	57	67

Present and Future Water Demand

(m^3/day)

	Water Demand		
Sub-areas	1995	2002	2007
Lobeysa	139	176	207
Bajo	44	56	66
Phangyul	52	66	78
Rubeysa	66	83	98
Total	301	381	449

Based on the above discussion, the future water demand in each sub-area is calculated as shown in the table. The total demands of 381 m^3/day and 449 m^3/day will be necessary in the target years of 2002 and 2007, respectively.

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FIGURES

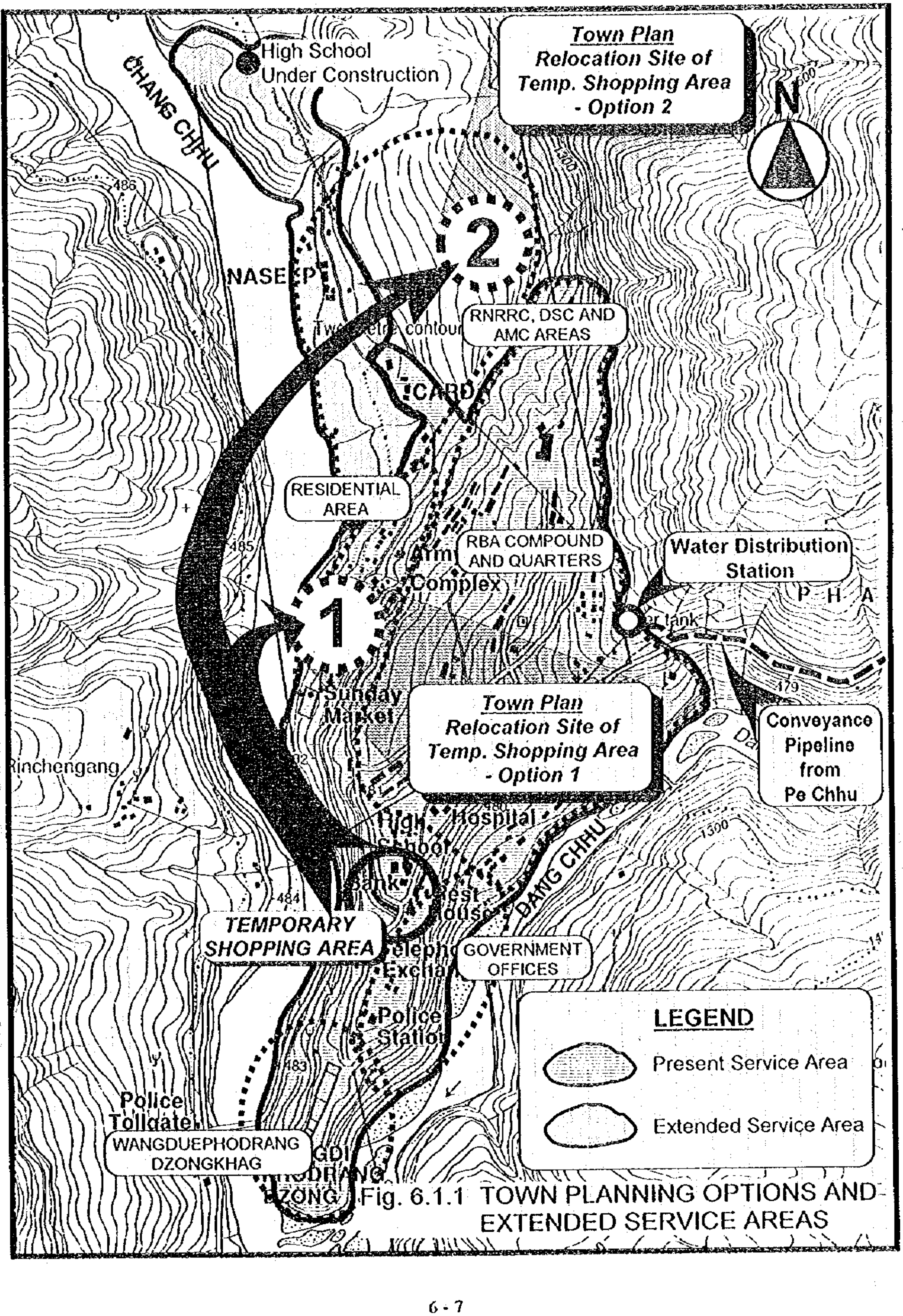


Fig. 6.1.1 TOWN PLANNING OPTIONS AND EXTENDED SERVICE AREAS

Categories	1995	2002	2007
1. Present Service Area			
Resident	6,035	6,932	7,654
Growth Rate (%)		(2.00)	(2.00)
Dayvisitors (38%)	2,293	2,634	2,908
Sub-total	8,328	9,567	10,562
2. Extended Service Area			
Resident	0	47	202
Dayvisitors	0	233	448
Sub-total	0	280	650
3. Total Population			
Resident	6,035	6,979	7,856
Dayvisitors	2,293	2,867	3,356
Total	8,328	9,847	11,212

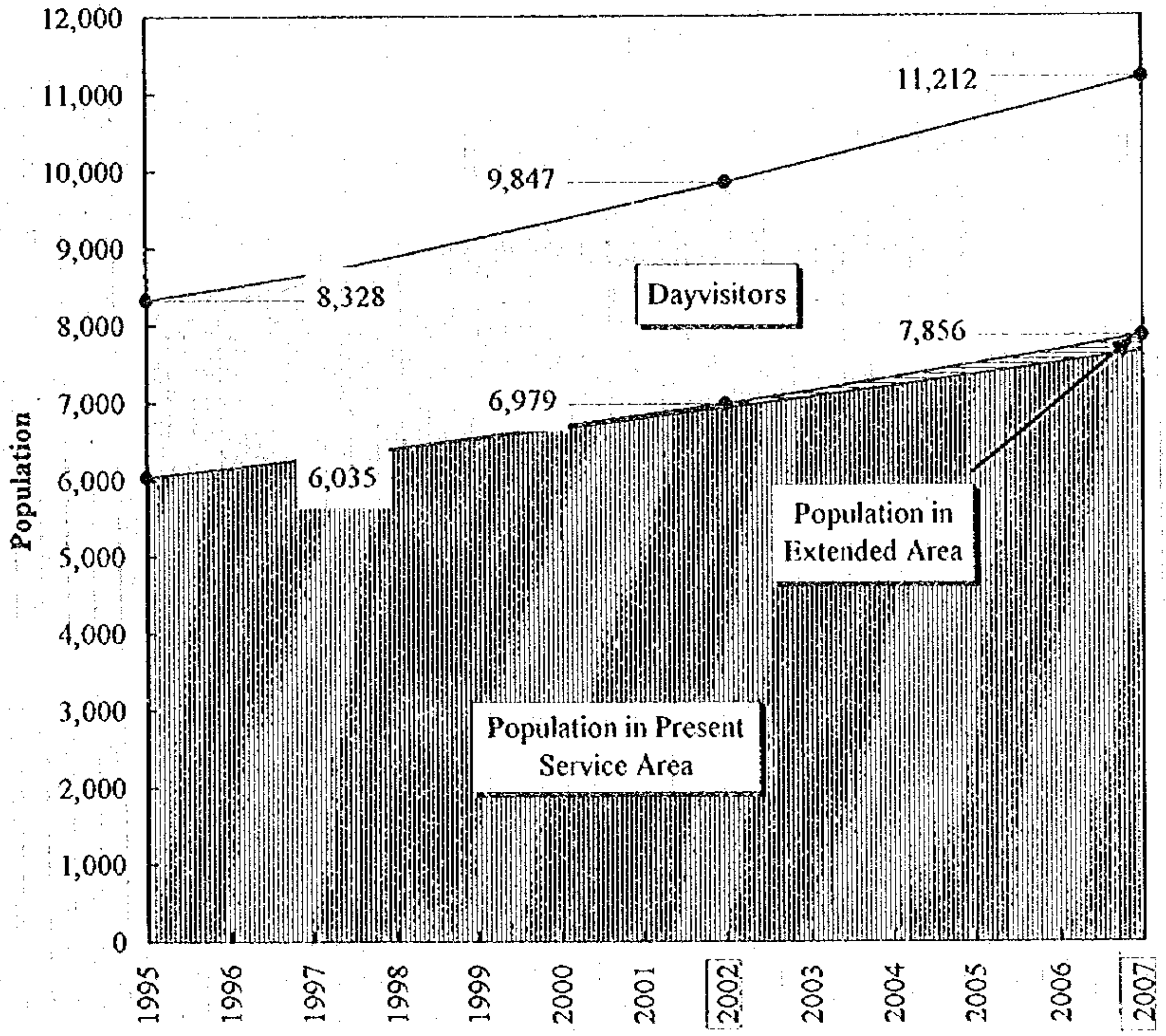
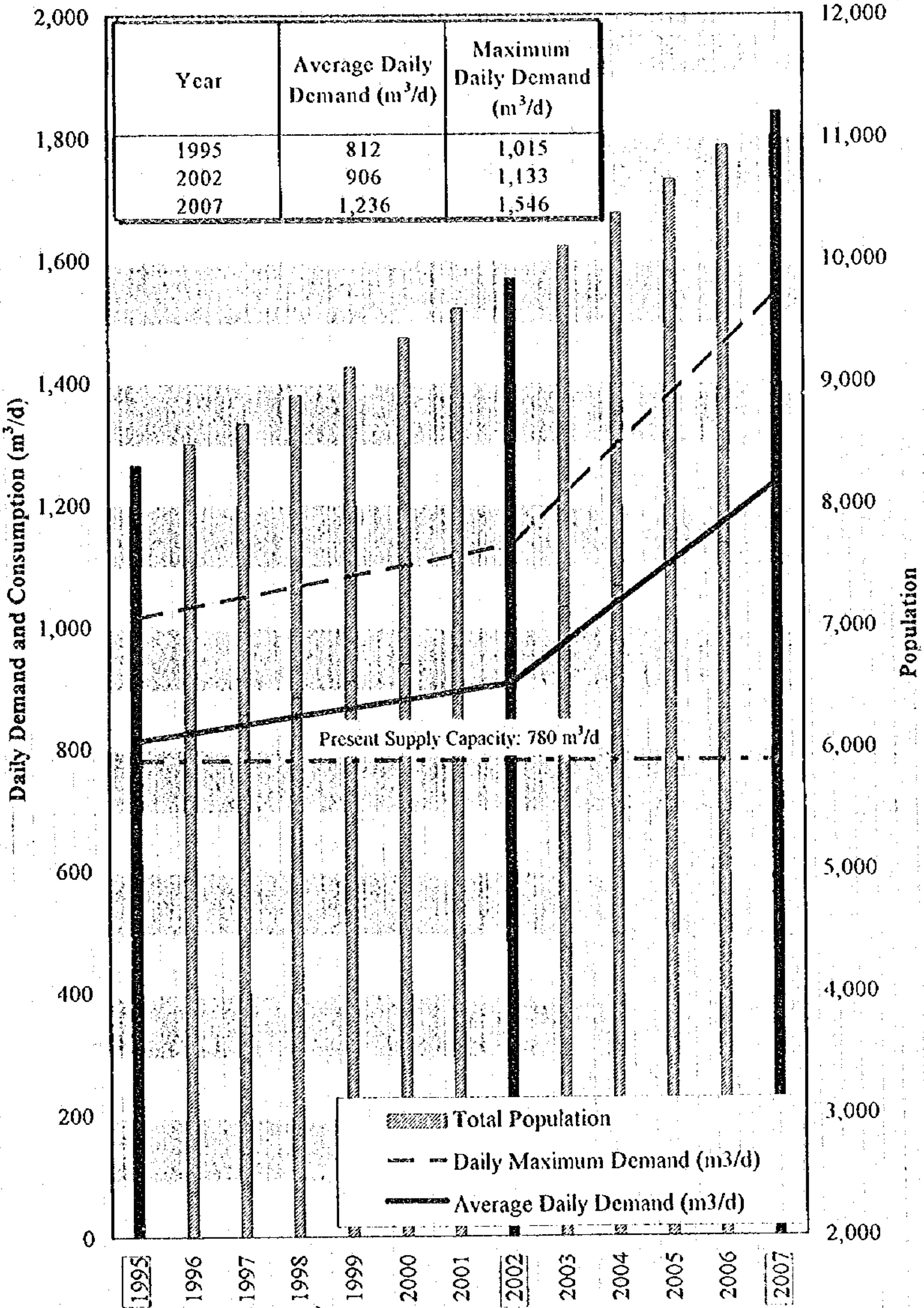


Fig. 6.1.2 POPULATION PROJECTION FOR WANGDUEPHODRANG TOWN AREA



Year	Average Daily Demand (m^3/d)	Maximum Daily Demand (m^3/d)
1995	812	1,015
2002	906	1,133
2007	1,236	1,546

Note: The above demands include 300 m^3/d for military use.

Fig. 6.1.3 FUTURE WATER DEMAND AND CONSUMPTION

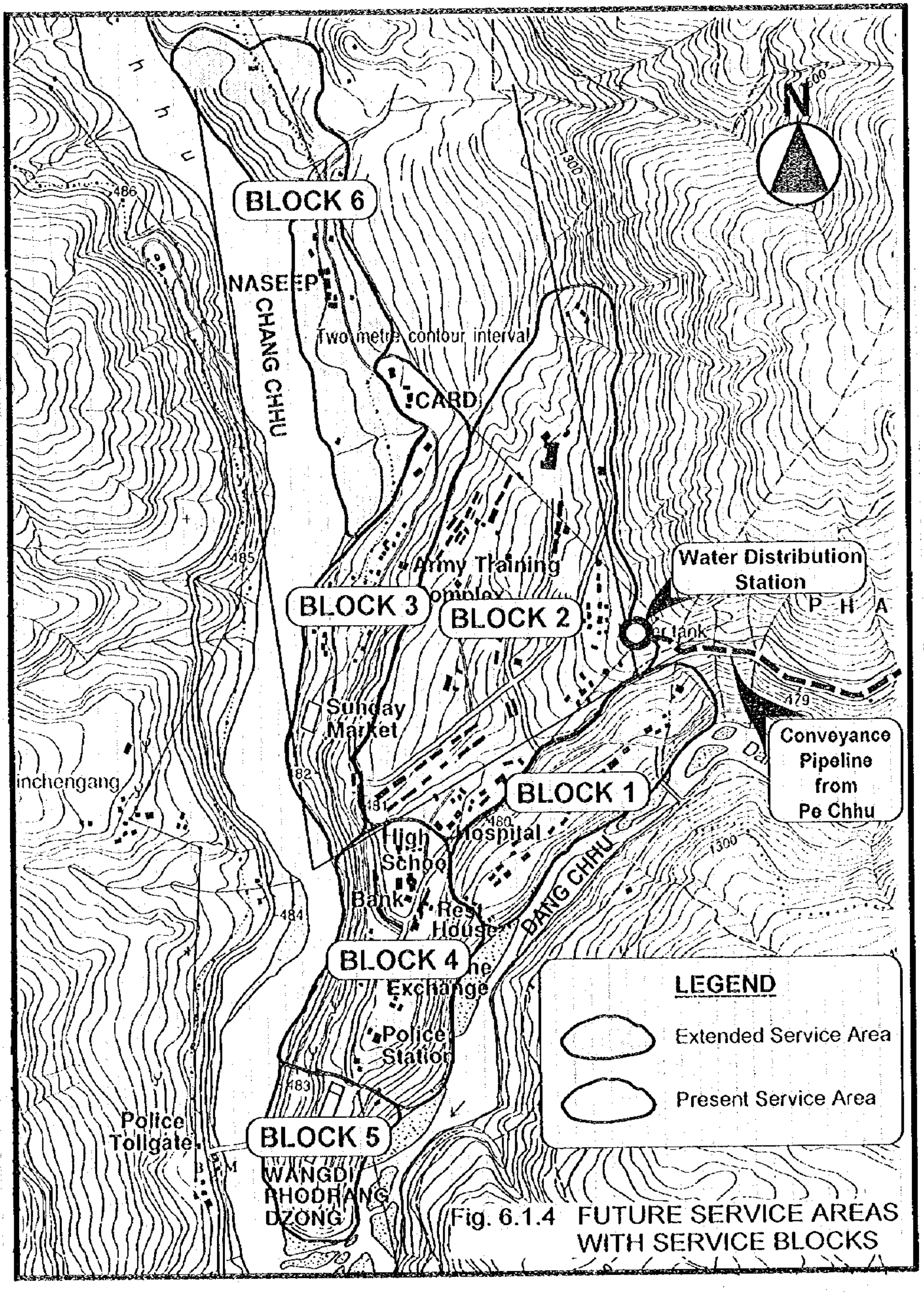


Fig. 6.1.4 FUTURE SERVICE AREAS WITH SERVICE BLOCKS

CHAPTER 7
WATER RESOURCES EVALUATION

7. Water Resources Evaluation

Considering the quantity and the quality of water as well as the impacts induced by its implementation, the water resources available in the Study area are broadly classified into two (2) categories. One is the surface water resource and another is the groundwater resource including sub-surface and spring water. Both categories of water resources are evaluated, and the following finding are reached.

- The surface water in low flat areas such as the Lobeysa and the Bajo sub-areas is considered sufficient, while that in hilly areas such as the Phangyul and the Rubeysa sub-areas insufficient even in the present water balance.

- The sub-surface water resources is abundant in the Bajo area, but it is not recommended to exploit it for irrigation, but for domestic water, because of its small potential comparing with the irrigation requirement.

- The spring water resources are recommended to be utilized for the rural water supply in the hilly areas such as the Phangyul and the Rubeysa sub-areas as much as possible.

- The groundwater in river terrace available in the Bajo sub-area is recommended to be utilized for the rural water supply, but economic and technical comparison with the sub-surface water is required.

- In the Lobeysa sub-area, the groundwater resources in mud-flow and the spring water are available. It is recommended to compare with each other on their economical and technical feasibility to determine the resources to be exploited.

- The water quality of groundwater is judged to be safe without any infection and contamination, while the surface water requires some treatment of disinfection and filtration.

- No adverse effect is predicted unless any excessive exploitation is made for the groundwater resources, but for the surface water some consideration may be necessary for reducing the high turbidity which may be caused by the construction of river structures.

The details of the evaluation are described below for each category of water resources.

7.1 Water Balance

7.1.1 Surface Water

At present, surface water is used mainly for the irrigation purpose and Wangduephodrang town water supply. Applying the present water requirement, the water balance for irrigation was analyzed as shown in Table 7.1.1. The details are discussed below for each sub-area.

(1) Lobeysa Sub-area

The maximum total water requirement of the upper and lower Lobeysa canals was estimated at 1.1 m^3/sec in May and the available river discharge of the Tabe Rongchhu was estimated at 3.2 m^3/sec which is 80 % of the mean river discharge of May at the intake site. Even if applying the double paddy cropping for all the paddy fields in the Lobeysa sub-area, the maximum water requirement becomes 0.9 m^3/sec in April (see Data Book V), and the available river discharge of May is estimated at 2.5 m^3/sec. In March, the lowest flow season, about 1.8 m^3/sec is estimated for the available river discharge, and the water requirement was estimated at 0.3 and 0.8 m^3/sec for both cases. Consequently, the sufficient water can be expected at the intake site for the irrigation purpose in the Lobeysa sub-area.

(2) Bajo Sub-area

The maximum total water requirement of the Bajo canal was estimated at about 0.5 m^3/sec in May and the available river discharge of the Pe Chhu was estimated at 3.9 m^3/sec which is 80 % of the mean river discharge at the intake site in May. Even if applying the double paddy cropping for all the paddy field in the Bajo sub-area, the maximum water requirement becomes 0.4 m^3/sec in April, and the available river discharge of May was estimated at 3.2 m^3/sec. In March, the lowest flow season, the available river discharge was estimated at 2.3 m^3/sec, and the water requirement was estimated at 0.1 and 0.4 m^3/sec for both cases. Consequently, the sufficient water can be expected at the intake site for the irrigation purpose in the Bajo sub-area.

As for the Wangduephodrang town water supply, at least 1.0 m^3/sec can be expected to be available for all the seasons, and this value is considered to be more than 50 times of the domestic water requirement in 2007 year.

(3) Phangyul Sub-area

As shown in Table 5.1.3, about 0.2 m^3/sec (70% of the water requirement) is estimated for the insufficient irrigation water in May, and 4 ~ 30 l/sec for January to March at the intake site of the Phangyul canal. It is technically possible to develop the new water source for this canal, but this is not considered feasible from the results of the Case Study in Appendix H.

As for the Gemkha canal, 20 l/s (around 45% of water requirement) of irrigation water is judged to be insufficient in May and there is no possibility to find out the other new water sources.

(4) Rubeysa Sub-area

As shown in Table 5.1.3, four (4) irrigation schemes have a problem of irrigation insufficiency of about 0.2 m^3/s (45% of the water requirement) in May, and there is no way to increase the diversion water, so are the canals in the Phangyul sub-area.