thickness, and the other major parts consist of a boulder bed with a thin intercalated bed of well-sorted sands.

c) Low Terrace

The low terrace with relative height of 2 m to 10 m from the river bed is widely distributed along the Chang Chhu.

The low terraces in the area are poorly covered by top soil. Microtopography as often found where natural levee, back swamp and ancient river channels (river beds) are present is clearly preserved on the terrace surfaces. Particularly in the case of ancient river channels which turn to wet land in the rainy season, indicating an interconnected subsurface water body between the groundwater and the current river water, this type of groundwater is considered as subsurface water or under flow.

The terrace is mainly composed of gravel beds with minor bands or lense of cross-bedded sands. The original topography such as ancient river channels is well preserved.

2) Mud-flow Deposits

The cultivated gentle slope in Lobeysa is formed by thick mud-flow deposits. Also, adjacent to the south of Lobeysa is another mud-flow deposit forming gentle slope where the camp of the Road Department is located

Aside from these major landslides, several mud-flow deposits are observed in the Study area. These mud-flows are quite uniform in constituent material and composed of unsorted, brown colored massive muddy sediments with angular blocks and fragments of rocks from the flow origin.

3) Fan Deposit

Small but clear fan deposits are observed in some places. The typical fan with considerably big size is only developed adjacent to the south of the Lobeysa mud-flow where the perennial spring at the terminal fan is observed. The geology of the fan is mainly less sorted debris or fanglomerate with sandy and/or muddy lenticular band.

3.4.3 Hydrogeology

(1) General

A hydrogeological survey has been conducted in the Study area during the Phase I, II and III field study. Those sites to be geophysically surveyed and the sites for the test drilling have been selected based on the results of the hydrogeological field survey of Phase I.

Since no systematic hydrogeological study has been carried out in the area in the past, no hydrogeological report is obtainable.

In this survey program, the following maps have been prepared.

- Hydrogeological Map : 1:50,000 (Fig. 3.4.4) and 1:10,000
- Groundwater Inventory Map : 1:10,000

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 and slightly or moderately permeable cover of the Quaternary age.

The basement rocks, probably Pre-Cambrian in age, are mainly composed of massive gneiss and foliated schist. The porosity of these basement rocks is generally in the form of foliation and/or interconnected fractures which vary considerably in size and frequency. These fractures become less frequent with depth, and as a rule, drilling deeper than 10 m after encountering the less fractured fresh rock is not advisable.

No important water yield from the basement rock has been observed in the Study area until now. Quaternary covers in the Study area are thickly weathered crest plane, river terraces landslide debris and less permeable mudflow deposits.

Quaternary river terraces along the Chang Chhu and other large river are the most important aquifer in this Study area. Since the area is located in the mountainous area, no impermeable bed/layer is intercalated in the terrace deposits, suggesting that the ground water in this area is unconfined.

(2) Springs

Many small springs yielding generally 5 l/min to 20 l/min are observed in the Study area.

Genetically, these water springs in the Study area could be classified into two (2) categories, the widely distributed landslide-related spring and the terminal fan type spring of which only one was found in Lobeysa.

1) Landslide Related Type Spring

Many landslides are distributed in the Study area. The flat or gentle terrain on the middle slope of mountains is mostly caused by landslide and is now being cultivated with spring water, which is used for both domestic and agricultural purposes.

The genesis of this type of springs has been geologically studied and the followings are the most likely interpretation.

During the sliding movement of the landslide, the sliding rockmass may have fractured causing higher porosity to form an aquifer. Meanwhile, at the bottom of the sliding mass, finely crushed rock and soil may form a clayey impermeable layer.

Thus, groundwater retained in the fractured landslide debris might be under-propped by the impermeable bottom layer of clay forming perched groundwater at the shoulder of the mountains.

In the field, all of these springs are found in muddy marshes with black slippery clay.

2) Terminal fan type spring

In the foot-hill region, many fans formed by debris flow or mud flow are generally found. At the toe of the geomorphological fan, referred to as the terminal fan, spring water pours out in many cases.

Adjacent to the south of the gentle terrain of Lobeysa, a small but distinct fan is observed covering the gentle terrain formed by mudflow deposits. At the terminal fan, a perennial spring pours out about 10 l/min of water benefiting several households and kitchen gardens.

(3) Groundwater (Aquifer)

The aquifers in the Study area can be classified into the following three (3) categories;

- River terrace related type
- Landslide debris related type
- Mudflow related type

1) River Terrace Related Type

Three levels of river terraces are recognized in the Study area as discussed in the other Chapters. Since no permeable layer is intercalated in the terrace deposits of the Study area, groundwater is only found at the bottom of permeable terrace deposits and the best yielding zone is situated just above the basement rock.

This observation suggests that the high terrace with the relative height of 130 m from the river bed is too elevated to host the groundwater.

The lower terrace, the youngest terrain in terms of geologic age, with relative height of 5 m to 10 m is poorly covered by soil. As a result, such areas are not well reclaimed and settlement is limited. Judging from these facts, the middle terrace is the only area of groundwater potential.

2) Landslide Debris Related Type

Landslide debris is a massive and highly porous geologic unit, mainly composed of blocks of fragments of weathered rock and lateritic soil as matrix. This physical character itself is excellent as an aquifer but the volume of each slide unit is too small to develop and utilize a large quantity of groundwater. The water yield of perennial springs utilized by villagers in the mountain area could be increased somewhat by trenching and draining at the marsh areas.

Because of the great variation in groundwater conditions of these kinds of small and isolated geologic units, it is difficult to generalize about the potential for spring water development. The volume of slide debris or the area of slide block is obviously the main factor controlling the water yield of this type.

In this study the annual recharge of groundwater is estimated as 440 mm. Therefore the area (square meters) multiplied by 0.44 m yields the annual groundwater recharge in cubic meters.

3) Mud-flow Related Type

Major mudflow deposits are distributed in the Lobeysa area, and several other smaller ones are observed in the Study area. The lithofacies of these mud-flow deposits are quite uniform in appearance. The included rocks vary in size from block to fragment and are scattered in muddy brown colored matrix. These facts suggest that the huge volume of water saturated materials have been transported in a short time.

Although the mud-flow deposits are less permeable, the huge volume of the massive sediments could be an excellent storage for groundwater. Groundwater retained in the mudflow deposits is underpropped by the basement rock and may have good potential yield of water at the zone just above the basement.

(4) Potential Areas for Groundwater Development

1) Area of Middle River Terrace along Chang Chhu

Among those aquifers mentioned above, the middle river terrace deposits may have the highest permeability and the best chance of recharge from the river water.

Furthermore, by careful study on the minor relief of the ground surface, one can safely delineate the ancient river channels which generally coincide with the buried/underground channel of groundwater flow.

Likewise, a topographic approach to interpreting the groundwater potential area is possible in the river terrace areas. Another hydrogeological approach to hit the groundwater flow is to find the underground depression of the surface of basement rock covered by the Quaternary sediments.

Because of absence of impermeable layers in the river terrace deposits of the area, the groundwater is unconfined, the course of which is controlled by the subsurface topography of the underlying impermeable basement rock.

Consequently, to detect the continuous depression engraved on the surface of the basement rocks geophysical explorations such as electric resistivity survey should be employed. This electric survey needs enough space to extend the wire for 200 m to 400 m.

2) Landslide Area

As discussed before, many small but perennial springs, genetically related to the landslides, are being utilized in many villages. The water in the slid debris is being recharged by precipitation as well as seepage from the forested background mountains.

Since the volume of debris is limited, the exploitable quantity of water is also limited. However, the spring water yield could be increased considerably by trenching if done in the correct way.

Since the groundwater is perched on the top of the clay layer of the landslide, the clay layer should not be disturbed. If a hole is punched in the clay layer the water will escape down the hole, just like pulling-out the plug of a bath tub.

A short distance upslope from the spring, the water table is shallow enough whereby the water is drawn up to the surface by capillary attraction and lost by evapotranspiration. In this zone, the so called capillary zone, a shallow trench of one (1) m to 1.5 m deep could reach the water level without damaging the underlying clay layer. The yield thereby becomes larger because the trench captures water that would otherwise be lost by evapotranspiration.

3) Mud-flow Deposit Area

These mudflow deposits have completely covered the pre-existing topographic relief, forming the new drainage/creeks which are far different from the buried drainage pattern. But the groundwater in these areas is still flowing down the buried creeks as mentioned above. This is the main reason for dry creeks often observed in the mud-flow areas.

To detect the deep buried ancient creeks, intensive geophysical exploration is necessary. These conditions make the exploitation of groundwater in the mud-flow area difficult and costly.

As a result, development of groundwater in the thick mud-flow area is not recommended except in the case of social or political necessity.

3.4.4 Geological Hazards Assessment

(1) General

The Himalayas are the youngest mountains in the world, still uplifting and under formation. Slopes will, therefore, generally be steeper and every infrastructure established is at a risk from washout and failure caused by erosion, gully intrusion, and landslide.

In Bhutan, glacial lake outburst, earthquake, flash-flood, and landslides constitute the main natural phenomena (geological hazards). These natural phenomena are mainly due to the natural causes but are accelerated in frequency and magnitude due to human interference with nature. The man-made structures tend to disturb the equilibrium of the regime of nature and nature in turn causes damaging effects to man-made structures.

The Study area is situated in the zone of the mountain and valley belt where nature has made deep gorges in the southern half and wide river valleys in the northern half of the zone.

In the Study area, with some exception, the cultivated area is composed mainly of foliating phyllite and schist, and brittle quartzite. The massive and resistant rocks overlying the brittle and foliating sequence are the crystalline limestone and the Himalayan gneiss. Those resistant rocks are distributed in higher altitude forming crests of ridges surrounded by steep slope.

In short, the Study area is composed mainly of weak rocks. Because of the weak geology, people have made terraces for cultivation on the gentle slope or fossil landslide area. Sometimes these fossil slides become active due to the road cutting or canal cutting at the toe part of the slide.

Since the Study area is of highly developed agricultural area, man-induced hazards will intensify. Especially the irrigation canals without lining may create landslides due to percolation and water load.

(2) Rating of Vulnerability

During the field survey period, a walk-over survey was carried out on the "rating of vulnerability", followed by (2) desk work on photogeological interpretation and slope analysis, and (3) vulnerability assessment.

In some part of the Study area, the natural process of mountain building and man induced physical impact to topography are causing the mass movement of soil and rock. These mass movements often cause washout and/or failure of linear infrastructures such as irrigation canals and roads.

Referring to the publications of the International Center for Integrated Mountain Development (ICIMOD), the check-list is prepared for field work on the rating for state of nature, which was later modified to rating of vulnerability as shown on Fig.

3.4.5. Special consideration was paid for selecting the observation items along the linear infrastructure (canal in this Study) which should be ranked in the field. For this reason the check list was simplified as much as possible.

After several times of trial rating along the same canal in the Study area, the simplified check-list composed of eleven (11) items to be judged in the field was finalized for the actual field use.

This simplified method, however inevitably relies on the experience-based subjective judgment to varying degree in rating. Furthermore, some logical discontinuities are intentionally employed to utilize the experience-based judgment, i.e., the old slide observed near by is allocated five (5) points while new slide within 20 m is given 8 points. Then the risk of new slide of 25 m apart should be classified as equivalent to either old slide or slide nearly 20 m apart.

(3) Field Survey Carried out

Walk-over field survey was carried out along the main canals in the Study area. Those canals surveyed are as follows:

List of Surveyed Canals

Name	Length	No. of Observed Segment
Phangyul canal	16.0 km	57
Gemkha canal	3.5 km	11
Bajo canal	15.0 km	47
Nalakha canal	3.9 km	13
Rutckha canal	2.2 km	13
Maphekha canal	2.2 km	10
Upper Lobeysa canal	7.1 km	29
Lower Lobeysa canal	8.1 km	15
Rumina	1.1 km	7
Naykogua	1.7 km	8
Total	60.8 km	210

In the field, each geomorphological unit was taken as a segment for the rating. Observation and judgment on each item of the check-list are converted to points as shown on the list and the total point value is treated as the vulnerability index.

During the field survey, the following items of works were carried out.

- Geological observation was supplementary conducted together with the rating.
- Critical section of danger was shown on the map by arrows and the length of possible damage is noted beside the arrow.
- Other phenomena observed carefully in the field are;
    - age of trees in the fossil slide zones to estimate the age of the slide
    - bending of tree trunks or leaning of the trees on slopes to estimate the movement of soil
- exposed roots of trees to estimate the depth of soil erosion

As a whole except some segments of the Bajo canal and the Phangyul canals, most of the canals are constructed in stable areas and no major damage is likely in near future.

The result of rating is compiled on the map of 1:10,000 together with the arrows showing the critical points of danger.

(4) Geological Hazards Map and Hazards Assessment

The results of field work on the rating for vulnerability of canals are compiled on the map of 1:10,000. Meanwhile, photogeological interpretation on the aero-photographs using a stereoscope as well as slope analysis around the canals were carried out on the desk.

The Geological Hazards Map is composed of several maps, i.e., geological map, slope analysis map and the map showing vulnerability index.

As discussed before, the concept of hazards includes the possible occurrence of triggers. But triggers such as earthquake or torrential downpour could not be predicted without continuous observation for many years. In this map the area shown by arrows indicates the highly hazardous zone which is selected in the field based on experience based judgment. Those figures of vulnerability index also indicate the hazardous degree of the segment.

Although some modification may be necessary when applied to other areas and/or other infrastructures such as road, the proposed check list for the vulnerability may provide reasonable standard for hazards assessment when it is utilized by the experienced geologist or civil engineer.

3.5 Meteorology

The climate of the Chang Chhu basin is classified into the following three (3) categories based on its altitude widely varying from 300 m to above 6,000 m as follows:

- Himalayan zone (altitude of above 3,000 m a.s.l) characterized by severely cold winter and short and cold summer. The area of the altitude of above 4,250 m is considered non-cultivable, and the snow area extends on the mountains above approximately 5,500 m. Any crop except cold resistance such as potato and barley can not grow in this zone.

- Temperate Himalayan zone (altitude of 1,500 to 3,000 m a.s.l) is characterized by moderately warm summer and cool winter. The annual rainfall thereof is varying from 500 to 1,200 mm. Rice, banana and orange grow in rather low areas, and broad-leaved trees are found in the southern slops of hilly area.

- Semi-tropical monsoon zone (altitude of 300 to 1,500 m a.s.l) is characterized by high temperature and humidity. The annual rainfall is observed as above 500 mm, and it sometimes reaches 2,000 mm. The tropical jungle covers most of the areas, but there are some dry areas like savanna.

The climate of the Study area (altitude of 1,200 to 2,800 m) has both characteristics of the temperate Himalayan and the semi-tropical monsoon. The mean monthly rainfall is higher from April to September than that from October to March, and these two (2) periods are generally referred to as the rainy and the dry seasons, respectively.

The meteorological parameters observed in the meteorological station at CARD (13640046, altitude 1,200 m) in Wangduephodrang which is located at the center of the Study area are summarized below.

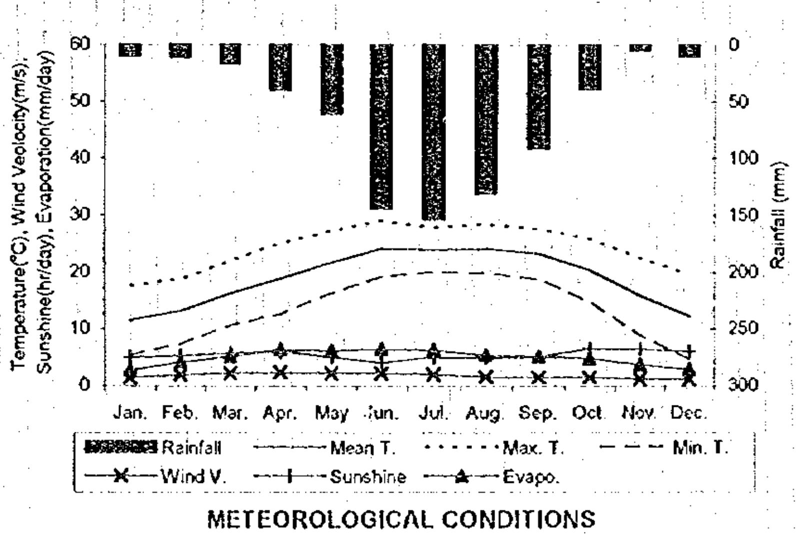
- Annual rainfall : 710 mm
- Mean Temperature : 19 °C
- Average Maximum Temperature : 24 °C
- Average Minimum Temperature : 13 °C
- Relative humidity : 75 %
- Wind velocity : 1.8 m/s
- Sunshine : 5.5 hr/day
- Evaporation : 1,790 mm/year

The annual distribution patterns of some selected parameters are summarized below.

Annual Distribution Pattern of Meteorological Parameters

Item	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Rainfall (mm)	10	12	16	40	61	144	153	130	91	39	5	10	710
Mean Temperature (°C)	11.5	13.1	16.3	18.9	21.8	24.1	24.0	24.2	23.2	20.4	15.8	12.3	18.8
Max. Temperature (°C)	17.6	18.8	21.9	25.1	27.3	29.1	27.9	28.5	27.7	26.0	22.6	19.7	24.3
Min. Temperature (°C)	5.4	7.4	10.7	12.6	16.3	19.1	20.0	19.9	18.8	14.8	8.9	4.8	13.2
Relative Humidity (%)	74.8	73.2	71.0	66.7	73.0	78.3	81.0	80.7	81.0	75.3	73.0	74.3	75.2
Wind Velocity (m/s)	1.4	1.9	2.2	2.3	2.2	2.2	2.0	1.6	1.5	1.5	1.2	1.2	1.8
Sunshine (hr/day)	5.0	5.2	5.7	6.1	5.1	4.1	5.1	5.0	5.2	6.6	6.5	6.0	5.5

The meteorological conditions in the Study area are illustrated below.



METEOROLOGICAL CONDITIONS

3.6 Hydrology

3.6.1 General

(1) Drainage System in Bhutan

There are the following four (4) major drainage systems in Bhutan.

- Manas Chhu basin
- Chang Chhu Sankosh basin
- Wang Chhu basin
- Amo Chhu basin

The Chang Chhu basin belongs to the Chang Chhu Sankosh basin, the second largest basin in the country. Most of the rivers originate in high mountain range of Himalayas of over 7,000 m a.s.l., and flow out to Bengal Bay passing the Indian and Bangladesh territories through Brahmaputra and Ganges rivers.

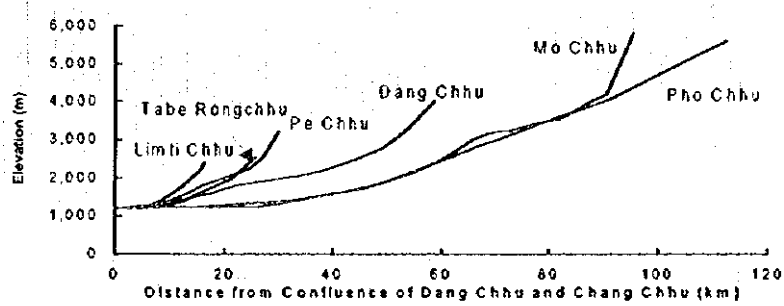
(2) General Conditions of Chang Chhu Basin

The Upper Chang Chhu basin defined in this Study as those river basins that are located at the upstream of Wangdue Rapids Stream Gauging Station of the Chang Chhu is divided into the following five (5) major sub-basins from north to south.

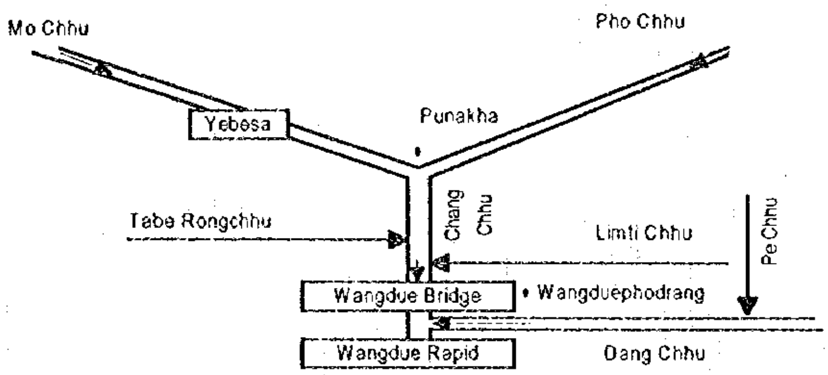
Chang Chhu Drainage System

Sub-basin	River and Tributary	Catchment Area (km^2)			River Length (km)
		Unit Basin	Sub-total	Total	
Mo Chhu	Mo Chhu at confluence	2,359	2,359		81.0
Pho Chhu	Pho Chhu at confluence	2,368	2,368		94.5
Pho - Mo Chhu Confluence				**4,727**	-
Chang Chhu	Tabe Rongchhu	121			17.7
	Limti Chhu	34			11.2
	Other Tributaries	73	228		14.5
Dang Chhu	Pe Chhu	158			21.6
	Dang Chhu	526	684		57.8
Chang - Dang Chhu Confluence				**5,639**	-
Chang Chhu (lower from Wangdue Bridge)	-	1			-
Chang Chhu at Wangdue Rapids		-		**5,640**	-

The total drainage area of the Upper Chang Chhu basin is measured to be 5,640 km^2 at the Wangdue Rapids Stream Gauging Station Site. The longitudinal profiles and the schematic diagram are shown below.



Longitudinal Profile of Chang Chhu River System



Chang Chhu Drainage System

.The present conditions of each basin of the Chang Chhu basin are briefed below.

1) Mo Chhu Sub-basin

The Mo Chhu sub-basin area is measured to be 2,359 km^2, and considered to be one of the largest sub-basin in Upper Chang Chhu basin. It originates in the glacier zone located at the north end of the country, the Himalayan Range of over 7,000 m a.s.l. The river flows through narrow and deep gorge southward joining many tributaries, and near Gasakatey meets the same Chhu flowing from Lingshi. The river runs southward to reach the confluence with the Pho Chhu at Punakha. The river length from the most upstream to the confluence with the Pho Chhu is measured to be about 81 km. A stream gauge station operated by Power Division is located at Yebesa, seven (7) km upstream of the confluence with the Pho Chhu. The drainage basin with an altitude of over 5,000 m is covered by snow throughout a year, while the other remaining parts are covered with well dense forest or little cultivated lands.

2) Pho Chhu Sub-basin

The Pho Chhu, which is also considered as one of the largest sub-basin in the Upper Chang Chhu basin, starts its flow in the glacier zone of Himalayan Range of over 7,000 m a.s.l, and flows southeastward in the high mountain range collecting drainage of glaciers. It changes its flow direction gradually toward south, and reaches the confluence with the Mo Chhu at Punakha joining the tributaries such as Si Chhu, etc. The drainage area is measured to be about 2,369 km^2 at the confluence. The basin is covered by deep forest consisting mainly of well-grown pine trees except for the snow-covered areas located in the high mountain ranges of over 5,000 m a.s.l. The distance from its uppermost reach to the confluence is measured to be about 95 km.

3) Tabe Rongchhu Sub-basin

The Tabe Rongchhu originates in the mountain range located east to Thimphu, and runs eastward along the narrow valley, and flows into the Chang Chhu near

Lobeysa. Many villages are scattered along the river and its small tributaries, and the cultivated land is developed. The vegetation of the basin is fairly good in upstream portion, but in lower reach near Lobeysa it becomes poor due to dry climate in Wangdue Valley. The distance to the confluence is measured to be about 18 km, and the drainage area is 121 km^2. There are many small intakes constructed by local farmers to divert river water for irrigating their cultivated lands along the river. Two (2) intakes; Lobeysa Upper and Lower canals are also located on the middle reach of this river.

4) Limti Chhu Sub-basin

The Limti Chhu originate in the hilly area of about 2,400 m a.s.l. near the Limbukha village which is located north to Bajo area. The river flows southward, and flows into the Chang Chhu in the Bajo area. The vegetation of its catchment area is not so dense, and the cultivated lands are expanded in the flat and sloped areas along the river. The river length is measured to be about 11 km, and the drainage area is 34 km^2.

5) Dang Chhu Sub-basin

At the Wangduephodrang town, the Dang Chhu which has an estimated drainage area of 684 km^2, flows into the Chang Chhu from the left bank. The Dang Chhu originates in the mountain area of about 5,000 m that is located at around 27°45'N and 90°15'. The river flows southward, changes its direction to west gradually, and flows into the Chang Chhu near Wangduephodrang town. At the point 7.5 km upstream of the confluence with the Chang Chhu, the Pe Chhu, which has a length and drainage area of about 22 km and 158 km^2, respectively, flows into this river. The total drainage area of the Dang Chhu at this confluence is measured to be 649 km^2.

The Pe Chhu is the important source of domestic water for Wangduephodrang town as well as the irrigation water for the Bajo area. Its intake facility is constructed on the Pe Chhu about one (1) km upstream of the confluence of the Dang Chhu and Pe Chhu, and an open channel and a pipeline of two (2) 10 cm-dia. steel pipes are installed along the foothill of Phangyul hill area to convey the intake water to the water treatment plant in Wangduephodrang town. The vegetation of this basin mainly consist of dense forest in the high mountain area of over 2,000 m, and in the low lands along the river cultivated lands are developed. At Wangdue Rapids which is located downstream of the Chang Chhu and the Dang Chhu, there exists a stream gauging station, and the total drainage area of the Chang Chhu basin at this station point is measured to be 5,640 km^2.

(3) Basin Condition of Study Area

The Study area of 65 km^2 is composed mainly of the Chang Chhu and the Dang Chhu basins. The Chang Chhu and the Dang Chhu flow from north to south and from east to west, respectively, and join each other at the south to the Wangduephodrang town.

The Chang Chhu, which flows through flat lands of the Bajo and the Lobeysa sub-areas, has two (2) perennial tributaries, namely the Limti Chhu on left bank and the Tabe Rongchhu on right bank. The Tabe Rongchhu has a drainage area of about 18 km^2, but most of the area extends out of the Study area. The Limuti Chhu originating in the Limbukha village is also considered similar to the Tabe Rongchhu, and most of its drainage area is located out of the Study area, though it has a drainage area of about 12 km^2. Since both sub-areas have limited and poorly vegetated areas of watersheds, most of rainfall in such sub-areas is judged to be drained rapidly to the Chang Chhu without any retarding.

On contrary, the Dang Chhu has a few flat planes along its course in the Study area, and both sides of bank are formed of steep and deep valley. The Phangyul and the Rubeysa sub-areas are located on elevated high hilly lands from 1,600 m to 2,000 m. The Phangyul sub-area has a limited area of Watersheds, and rainfall in this area is considered to be drained rapidly to the Dang Chhu similar to the other sub-areas in the Chang Chhu basin. The rainfall in these elevated lands are expected to be larger than those in other two (2) sub-areas in the Chang Chhu basin due to their altitude.

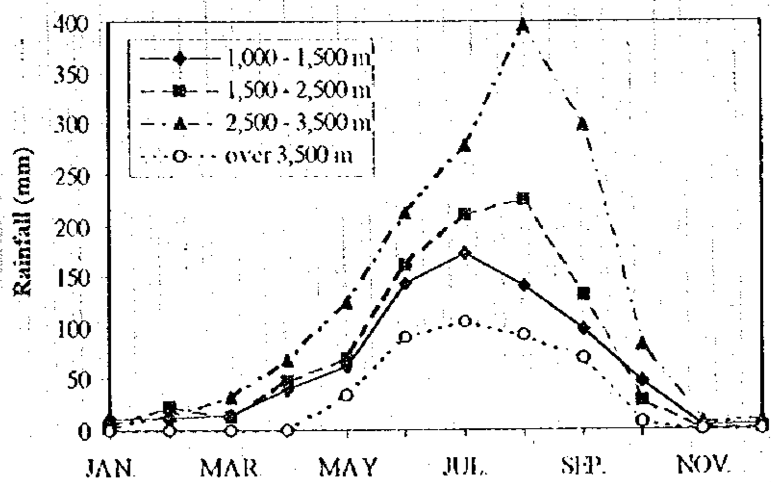
3.6.2 Rainfall

The annual rainfall in the basin varies from place to place depending on its altitude as tabulated in the right table.

Estimated Rainfall in the Study Area

Altitude	Annual Rainfall (mm)
1,000- 1,500 m	700
1,500 - 2,500 m	1,200
2,500 - 3,500 m	1,800
over 3,500 m	500

Using the rainfall data at the stations in the Wangdue Valley, annual rainfall pattern in the Chang Chhu basin was roughly estimated as shown below.



EXPECTED ANNUAL RAINFALL PATTERN

Based on the estimated rainfall and altitude, the rainfall pattern in the Study area and at intake site was estimated as shown below.

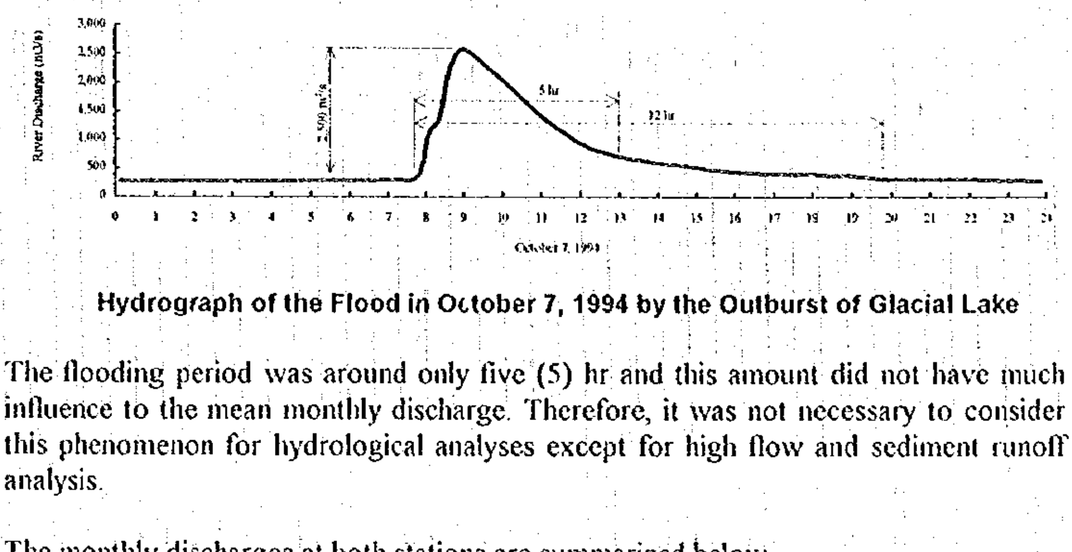
Estimated Rainfall Pattern in the Study Area and at Intake Site

Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Study Area	8	26	17	56	83	193	249	256	153	39	2	4	1,086
Bajo Intake Site	6	22	28	68	120	228	297	384	271	71	6	8	1,509
Lobeysa Intake Site	7	25	26	68	113	226	295	363	245	63	5	7	1,442
Phangyul Intake Site	6	21	33	75	135	243	316	433	315	86	7	10	1,680

3.6.3 Runoff

Approximately 1,500 mm and 1,600 mm of annual runoff were estimated at Wangdue Rapids on the Chang Chhu and at Yebesa on the Mo Chhu, respectively. These values are considered approximately twice of rainfall at Wangduephodrang. Taking into account of the present basin conditions, the runoff of the basin may be affected by those from glaciers in high mountains.

An extraordinary flood occurred on the October 7th, 1994, because of the outburst of glacial lake named Lugge which is attached to the glacier and is located on the eastern tributary of the Pho Chhu and the maximum flood discharge was estimated as more than 2,500 m^3/s. This amount of discharge might be more or less 3 ~ 4 times larger than that of usual flood in the rainy season. According to the discharge data of DOP, the hydro pattern on that day are shown as below;



Hydrograph of the Flood in October 7, 1994 by the Outburst of Glacial Lake

The flooding period was around only five (5) hr and this amount did not have much influence to the mean monthly discharge. Therefore, it was not necessary to consider this phenomenon for hydrological analyses except for high flow and sediment runoff analysis.

The monthly discharges at both stations are summarized below.

Summary of River Discharge Data

13490045 Wangdue Rapids on Pho-Mo Chhu
5,640 km^2 1,190 m 27-2745N 89-5411E (Unit: m^3/s)

Item	Jan.	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep.	Oct	Nov.	Dec	Annual
Mean	71.8	63.9	75.4	118.7	197.0	319.3	518.3	710.7	528.1	265.1	130.4	90.5	257.4
Max.	83.5	75.1	138.7	1114.8	329.0	790.6	935.2	1163.6	964.0	2539.2	181.7	119.6	2539.2
Min.	64.5	55.0	54.7	67.7	124.3	153.6	232.6	428.1	270.5	158.5	98.9	71.8	54.7

13700045 Yebesa on Mo Chhu
2,320 km^2 1,230 m 27-3759N 89-493E (Unit: m^3/s)

Item	Jan.	Feb.	Mar	Apr.	May	Jun	Jul	Aug	Sep.	Oct	Nov.	Dec	Annual
Mean	27.8	25.6	31.1	44.6	83.1	155.7	209.2	302.4	217.1	99.2	49.4	33.4	106.6
Max.	31.1	32.5	61.1	81.3	166.0	305.6	448.3	483.2	432.3	175.7	72.4	44.6	483.2
Min.	25.9	22.4	23.2	28.1	44.1	66.2	101.5	140.1	99.9	54.0	34.4	25.0	22.4

In the lowest flow season, the difference between monthly maximum and minimum discharges is found to be within the range of less than +/-10 % of monthly mean discharge, while in the high flow season it reaches to a range from +/-40 to 50%.

From the result of Tank Model analysis, the annual water balance at Wangdue Rapids in the Chang Chhu is roughly estimated as presented in the table.

Summary of Water Balance of Chang Chhu

(mm/year)

Rainfall and Snowfall	2,400
Evaporation and Others	1,100
Runoff from Precipitation	1,300
Runoff from Glaciers	200
Total Runoff	1,500

Based on the result of Tank Model analysis, the monthly discharge for 10 years were estimated and the results are summarized as shown below.

Monthly Discharge at Wangdue Rapids (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

Based on the existing hydrological data, the specific discharge in the Study area was estimated as shown below.

Estimated Specific Discharge in the Study Area

(unit : $m^3/s/km^2$)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Specific Q	0.022	0.021	0.019	0.027	0.034	0.067	0.104	0.140	0.114	0.051	0.036	0.025

Using this specific discharge, the river discharge at intake site was estimated as shown below.

Estimated Monthly River Discharge at Intake Site

(unit : m^3/s)

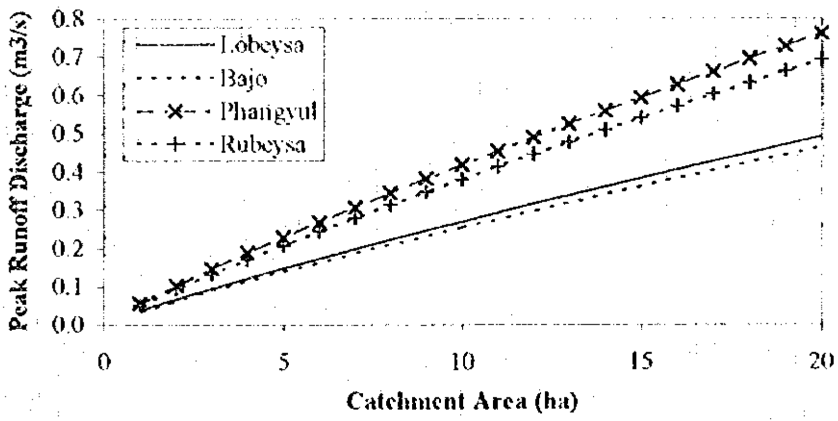
River	C.Area(km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Taberong Chhu	119.40	2.602	2.500	2.327	3.231	4.034	8.028	12.453	16.755	13.577	6.067	4.286	3.029
Pe Chhu	145.70	3.175	3.051	2.840	3.943	4.922	9.797	15.196	20.446	16.568	7.403	5.230	3.696
Lachhu	2.23	0.048	0.047	0.043	0.060	0.075	0.150	0.232	0.312	0.253	0.113	0.080	0.056
Uship	4.18	0.091	0.087	0.081	0.113	0.141	0.281	0.435	0.586	0.475	0.212	0.150	0.106
Mochuna	8.78	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	6.80	0.148	0.142	0.133	0.184	0.230	0.457	0.709	0.954	0.773	0.346	0.241	0.172

Using Rational Formula, the peak runoff discharge of the main rivers for average year was estimated as shown in the table.

Estimated Peak Discharge at Main Rivers

Max. 24 hr Rainfall (mm)			58.8		
River	Catchment Area (km^2)	Duration Time (hr)	Rainfall Intensity	Peak Runoff (m^3/s)	Specific Q ($m^3/s/km^2$)
Pe Chhu	158	40.69	1.88	41.292	0.261
Limti Chhu	34	27.01	2.31	10.905	0.321
Tabe Rongchhu	121	37.89	1.95	32.767	0.271

There are several tributaries in the Study area and the direct runoff from the rainfall is drained through these tributaries. The direct runoff comes from the agricultural land and the amount of the peak runoff should be varied depending on the scale of catchment area. Using the Rational Formula above mentioned, the relationship between the catchment area and the peak runoff discharge was analyzed as illustrated below.



ESTIMATED PEAK RUNOFF FROM AGRICULTURAL LAND

Using the result of the low and high flow analyses at Wangdue Rapids, the probability analysis was carried out for the Chang Chhu and other rivers. The results are summarized below.

Result of Runoff Probability Analysis at Chang Chhu and Dang Chhu

(m^3/s)

Site	Wangdue Rapids			Upper Part of Chang Chhu			Dang Chhu		
Catchment Area (km^2)	5,640			4,956			684		
Return Period	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
1/500	191.7	2017.3	36.8	168.4	1772.6	32.3	23.2	244.7	4.5
1/200	198.1	1858.8	38.4	174.1	1633.4	33.7	24.0	225.4	4.7
1/100	203.7	1741.2	39.8	179.0	1530.1	35.0	24.7	211.2	4.8
1/50	210.4	1625.0	41.4	184.8	1428.0	36.4	25.5	197.1	5.0
1/20	221.2	1472.6	43.9	194.3	1294.0	38.6	26.8	178.6	5.3
1/10	231.7	1356.1	46.2	203.6	1191.7	40.6	28.1	164.5	5.6
1/5	245.9	1235.4	49.2	216.1	1085.6	43.2	29.8	149.8	6.0
1/2	277.9	1054.9	55.5	244.2	927.0	48.8	33.7	127.9	6.7

Result of Runoff Probability Analysis of Other Rivers

(m^3/s)

Site	Pe Chhu			Limti Chhu			Tabe Rongchhu		
Catchment Area (km^2)	158			34			121		
Return Period	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
1/100	5.708	176.26	1.115	1.228	46.55	0.240	4.371	139.87	0.854
1/50	5.893	148.26	1.159	1.268	39.16	0.249	4.513	117.65	0.888
1/20	6.195	114.50	1.229	1.333	30.24	0.264	4.745	90.87	0.941
1/10	6.492	91.15	1.295	1.397	24.07	0.279	4.972	72.33	0.991
1/5	6.889	69.27	1.379	1.483	18.29	0.297	5.276	54.97	1.056
1/2	7.785	41.29	1.555	1.675	10.91	0.335	5.962	32.77	1.191

Using the river section and the results of probability analysis, the river flow at the Chang Chhu was analyzed by applying the non-uniform flow calculation. The flow conditions at the river pump station in RNRRC are summarized below.

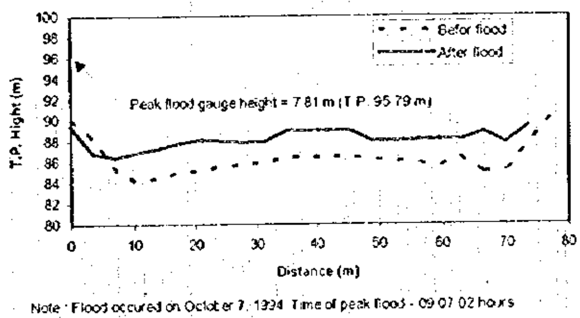
Estimated Water Level at RNRRC River Pump Station

(Unit: TP.m)

Return Period	River Bed	1/500	1/200	1/100	1/50	1/20	1/10	1/ 5	1/ 2
Mean flow	1,193.4	1,195.9	1,195.9	1,196.0	1,196.0	1,196.1	1,196.2	1,196.3	1,196.5
Max. flow	1,193.4	1,200.5	1,200.2	1,199.9	1,199.6	1,199.3	1,199.0	1,198.7	1,198.2
Min. flow	1,193.4	1,194.9	1,194.9	1,194.9	1,194.9	1,194.9	1,194.9	1,194.9	1,195.0

3.6.4 Sediment Runoff

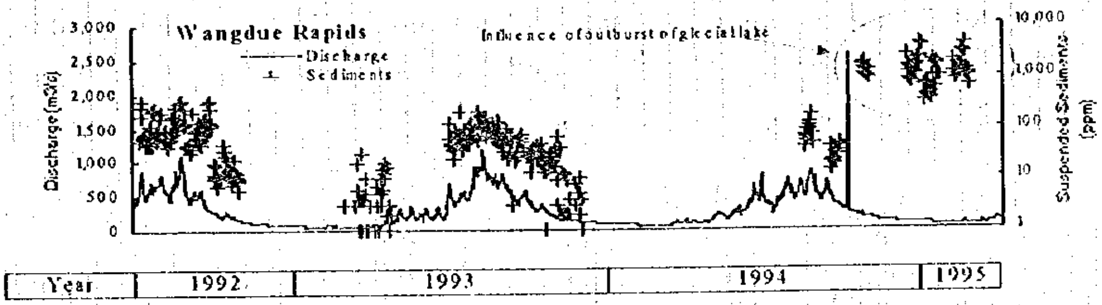
As mentioned before, the extraordinary flood occurred on October 7, 1994 caused by outburst of glacial lake and flood affected so much that the river bed of the Chang Chhu rose up by more than one (1) m at Wangdue Rapids due to the sedimentation as shown in the figure.



Note: Flood occured on October 7, 1994. Time of peak flood - 09:07:02 hours

CROSS SECTION PROFILE OF WANGDUE RAPIDS BEFORE AND AFTER FLOOD

The river condition was changed drastically as soon as this flood. Furthermore, the suspended sedimentation load (SS) has risen up by 100 ~ 1000 times of those before the flood, and this phenomenon has still continued even for six (6) months later as indicated below.



Therefore, it is necessary to neglect the SS data series after the flood for sediment runoff analysis in the Chang Chhu basin.

Using the suspended sediment and the river discharge data at Wangdue Rapids and Yebesa, the relationship between river discharge and suspended sediment was analyzed. The results are summarized below.

- Wangdue Rapids $SS = 0.00884 \times Q^{2.009}$ (Correlation Coefficient: 95 %)
- Yebesa $SS = 0.01086 \times Q^{2.091}$ (Correlation Coefficient: 86 %)

where; SS : Suspended Sediment (t/day)
Q : Daily Mean Discharge (m^3/s)

The sediment runoff at both stations was estimated using the actual daily discharge data and above equations. Approximately 414,000 t of annual sediment runoff was estimated at Wangdue Rapids and this amount is equivalent to about 745,000 m^3/year (110 m^3/km^2/year). On the other hand, approximately 140,000 t was estimated at Yebesa and this also is expected to be 252,000 m^3/year (100 m^3/km^2/year).

3.7 Agriculture

3.7.1 Land Use in the Study Area

The land use in the Study area was measured using the land use working map from the Land Use Section, as shown below.

Land Use in the Study Area (ha)

Category	Study Area		Sub- Area							
			Lobeysa		Bajo		Phanguyl		Rubeysa	
1 Forest	4,066	(62.6%)	10	(2.4%)	12	(6.3%)	769	(68.1%)	440	(50.6%)
2 Agriculture										
Wetland Cultivated	1,099	(16.9%)	216	(52.8%)	161	(85.2%)	151	(13.3%)	218	(25.1%)
Dry land Cultivated	0	(0.0%)	0	(0.0%)	0	(0.0%)	8	(0.7%)	70	(8.0%)
Other Agriculture	471	(7.2%)	132	(32.3%)	5	(2.6%)	115	(10.2%)	43	(4.9%)
Sub-Total	1,570	(24.2%)	348	(85.1%)	166	(87.8%)	274	(24.2%)	331	(38.0%)
3 Orchard & Horticulture	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
4 Pasture	253	(3.9%)	35	(8.6%)	0	(0.0%)	87	(7.7%)	80	(9.2%)
5 Settlement	93	(1.4%)	-	-	-	-	-	-	-	-
6 Others	518	(8.0%)	16	(3.9%)	11	(5.8%)	-	-	19	(2.2%)
Total Area	6,500	(100.0%)	409	(100.0%)	189	(100.0%)	1,130	(100.0%)	870	(100.0%)

Note : Area was estimated based on the data base of the Land Use Planning Project

The land use of the Study area and sub-areas are illustrated in the Fig. 3.7.1, and the followings were found out during the field work.

(1) Lobeysa and Bajo Sub-areas

Most of the areas of the Lobeysa and the Bajo sub-areas are utilized as agricultural land covering 85.1% and 87.8% of the sub areas respectively. Most of the cultivated areas within agricultural land are utilized as irrigated wetland and are located at the bottom of the valley. The forest area covers only a small area of these sub-areas.

(2) Phangyul and Rubeysa Sub-areas

Some parts of the Phangyul and the Rubeysa sub-areas are utilized as agricultural land, which occupy 24.2% and 38.08% of the sub-areas respectively. Agricultural land in these sub-areas is located in the mountainous area, which has a relatively gentle slope. The forest area covers 68.1% and 50.6% of the sub-areas, respectively. Coniferous forest is found in the lower parts of these sub-areas, while broadleaf forest is found in the upper parts.

3.7.2 Present Agricultural Activities

(1) Present Cropping Pattern

Crop season in the Study area is broadly divided into two (2) seasons; monsoon (rainy) and winter (dry) seasons. The present cropping pattern in the sub-areas is illustrated in Fig. 3.7.2.

The main crop grown in the monsoon season is paddy, followed by winter crop (mainly wheat and mustard). In the upland area which is under rainfed condition, the main crop in the monsoon season is vegetables, but only a few areas exists. Recently, some irrigation canals have been improved under the Punakha - Wangdue Valley Development Project financed by IFAD and in some areas irrigation becomes possible throughout the year. In these areas, it is possible to start land preparation for paddy even in February during the winter season, and double cropping of paddy is carried out even though such areas are considered small.

Present major cropping patterns in the Study area are as follows:

i) Paddy - Wheat
ii) Paddy - Mustard
iii) Paddy - Fallow
iv) Paddy - Vegetables
v) Vegetables - Wheat

Paddy occupies about 95 % of irrigated area during the monsoon season. The planted area of crops in the sub-areas are tabulated below.

Planted Area by Crops

Crop	Lobcysa		Bajo		Phangyul		Rubcysa		Total
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	
Paddy	285	-	112	-	64	-	131	-	592
Wheat	-	121	-	52	-	29	-	58	260
Mustard	-	33	-	14	-	8	-	16	71
Others	15	15	6	6	3	3	7	7	62
	300	169	118	72	67	40	138	81	
Total	469		190		107		219		985

(2) Present Farming Practice

Most farmers plant local varieties of paddy. Maap is a local red rice variety and Kaap is local white rice variety. Most people prefers the taste of local red rice (Maap). Usually the farmers prepare the seeds by themselves. In case of the improved varieties of paddy, RGOB promots improved varieties such as IR64, No.11, IR20913, etc., and distributs seeds to farmers through the Agriculture Extension Center under Dzongkhag.

1) Paddy Cropping

The land preparation for single paddy cropping is started in the beginning of the monsoon season which is generally in the middle of May, and the land preparation is carried out from the higher part of area where water is supplied from existing canals. Depending on the amount of canal water discharge, it takes one or one and half months for the land preparation of all paddy area. The transplanting is started after land preparation from the upper part to lower part, resulting in a difference of about one to one and half months in the cropping period between upper and lower parts. Usually, surplus water of upper terrace is effectively reused in the next lower terrace.

2) Winter Crop

As a result of interview survey, it was found out that the winter crop such as wheat (variety: Bajoka, Sonalika, Local) mustard and vegetables are planted after rice harvesting which is generally in the middle of October. The winter crop is also irrigated depending on the weather conditions, and the amount of canal discharge is quite low in that season but is generally enough for seeding.

3) Vegetables in Monsoon Season

The vegetables of the monsoon season are cropped only in the areas with high altitude where irrigation water cannot be obtained from any canal or small stream. These depend on the seasonal rainfall and the seeding is carried out with the first rainfall in April or May. Production also depends on the rainfall condition.

4) Double Cropping of Paddy

Double cropping of paddy is followed in the areas with the improved irrigation canals constructed by the IFAD Project; especially, sufficient irrigation water is available throughout the a Depending on the climate conditions, land preparation is carried out in the middle of February. The first rice cropping is harvested in July and the second rice cropping is started soon after.

According to the data obtained during the survey, the area under double paddy cropping has increased from 1987 in the Punakha - Wangdue Valley, but double cropped area has declined from 1992. The reason for this is reported that double cropping is possible only where there is sufficient man power. Accordingly double cropping has been well adopted for farmers with small land holdings. Hence, farmers with bigger land holdings can produce sufficient rice for their own consumption by single cropping of rice.

5) Agricultural Equipment

Various agricultural tools, instruments and equipment are also used to improve the farming works. Due to road accessibility and more favorable topography, power tillers are used for land preparation in the Lobeysa and Bajo sub-areas.

In contrast, cattle plowing is common in the Phangyul and Rubeysa sub-areas. Power tillers with trailer are used for transportation of agricultural inputs (green manure, chemical fertilizer, etc.) and outputs.

6) Livestock

Cattle perform the most important role for farmers as draft animals and for milk production in the Study area. Most farm households have several horses, pigs and poultry. There are certain numbers of cattle which do not produce viable amounts of milk and instead are used for the production of manure.

Cattle are classified into three (3) categories; local cattle, cross bred cattle and methane cattle. The most prevailing is considered to be local cattle. RGOB is promoting breed improvement, fodder and pasture development, etc., to increase output of livestock products. Rice straw is used for livestock feed in the feed-scarce winter season and wheat straw is used for livestock bedding.

(3) Crop Yield and Production

The Gewog-wise data on planted areas, yields and production of paddy, wheat and mustard in the Study area were obtained from the Agriculture Sections of the Wangduephodrang Dzongkhag and RNRRC. The yield and production of the four (4) Gewogs; Thedtsho, Rubeysa and Phangyul Gewogs in Wangduephodrang Dzongkhag, Babesa Gewog in Thimphu Dzongkhag and the whole of the Wangduephodrang Dzongkhag are estimated below.

Yield and Production of Major Crops

	Paddy			Wheat			Mustard		
Gewog	Area(ha)	Prod.(t)	Yield(t/ha)	Area(ha)	Prod.(t)	Yield(t/ha)	Area(ha)	Prod.(t)	Yield(t/ha)
Bapisa	93	248	2.67	16	21	1.31	5	5	1.00
Phangyul	400	1265	3.16	34	50	1.47	10	8	0.80
Thedtsho	400	1267	3.17	15	22	1.47	6	5	0.83
Rubeysa	630	1992	3.16	44	66	1.50	14	12	0.86

Based on these data of crop yield and production, production of each sub-area was estimated as follows:

Crop Yield and Production in Each Sub-area

	Paddy			Wheat			Mustard		
Sub-Area	Area(ha)	Yield(t/ha)	Product(t)	Area(ha)	Yield(t/ha)	Product(t)	Area(ha)	Yield(t/ha)	Product(t)
Lobeysa	285	2.67	760	121	1.31	159	33	1.00	33
Bajo	112	3.16	354	52	1.47	76	14	0.80	11
Phangyul	64	3.17	203	29	1.47	43	8	0.83	7
Rubeysa	131	3.16	414	58	1.50	87	16	0.86	14
Total	592	-	1,731	260	-	365	71	-	65

Paddy production was estimated as 1,731 t in the above four (4) sub-areas and average yield was estimated as 2.90 t. Total production of wheat is 365 t and yield is 1.40 t/ha in the same four (4) sub-areas. In the case of mustard, production is 65 t and yield is 0.91 t/ha. The vegetables grown in the Study area are chili, tomato, onion, radish, cabbage, cauliflower, beans, etc. These vegetables are cultivated in small fields or kitchen gardens near farm houses.

3.8 Water Supply

3.8.1 Urban Water Supply for Wangduephodrang Town Area

(1) Water Supply System

Fig. 3.8.1 shows the location and layout of the urban water supply system for the Wangduephodrang town area. The supply system was constructed in 1969 with the assistance of India diverting the river water from the Pe Chhu, a tributary of the Dang Chhu. The system consists mainly of intake facilities, conveyance pipelines, water distribution station and distribution networks in the town area as summarized below.

1) Intake Facilities

The intake is situated at right bank of the Pe Chhu, 1.6 km upstream from the Chhuzonsa, where the Pe Chhu flows directly into the Dang Chhu. The river water flows into the open canal directly by gravity, and the water for domestic water supply is again diverted from the canal to the grit chamber for removing coarse sands and heavy suspended solids. The irrigation water flows in the open canal to the command area in the Bajo sub-area.

2) Water Conveyance Pipelines

The Bajo irrigation canal was used for conveying the domestic water also, when the supply system was constructed in 1969. Due to deterioration of water quality corruption, about nine (9) km of 4"-steel-made high density polyethylene (HDPE) pipeline was constructed along the national road between Chhuzonsa and Wangduephodrang in 1991 under the UNICEF cooperation. At present, the domestic water is conveyed mainly by the pipelines.

3) Water Distribution Station

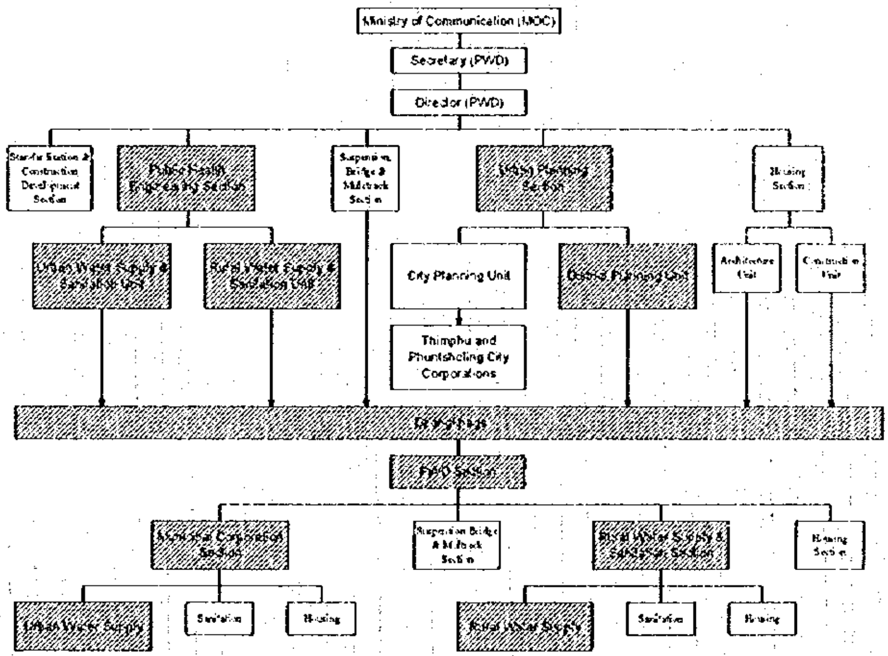
The water distribution station for the Wangduephodrang town area consists mainly of plain sedimentation tanks with a total capacity of 950 m^3, and water distribution tanks with a total capacity of 600 m^3.

4) Water Distribution Network

According to the Dzongkhag PWD section, the pipeline networks over 6,500m long was installed in 1969 for distributing the treated water to the houses, offices, etc., consisting of steel galvanised pipes (SGP) and high density polyethylene pipes (HDPE).

(2) Operation and Maintenance of Water Supply System

An intermittent water supply is conducted at present for operating the water supply system in the Wangduephodrang town area. Three (3) times of supply is made a day; three (3) hr in the morning, 2.5 hr for lunch time, and two (2) hr in the evening, totaling 7.5 hr a day. The operation and maintenance of the supply system is managed by the PWD section of the Wangduephodrang Dzongkhag as shown below.



ORGANIZATION CHART OF CITY, URBAN AND RURAL WATER SUPPLY

3.8.2 Water Supply System for Rural Areas

(1) Villages and Communities Identified

The total of 64 villages/communities were identified in the whole Study area; 21, 8, 18 and 17 villages/communities in Lobeysa, Bajo, Phangyul and Rubeysa sub-areas, respectively. The number of households and population were estimated as 627 and 6,684, respectively in the whole Study area. The locations and the

Summary of Identified Villages/Communities

Villages/Communities	Present Population Household	Present Population Populat-ion	Villages/Communities	Present Population Household	Present Population Populatio n
Lobeysa Sub-area	177	3,086	Phangyul Sub-area	156	1,159
Babesa Gewog	134	2,604	Phangyul Gewog	156	1,159
Thetso Gewog	43	482			
Bajo Sub-area	115	983	Rubeysa Sub-area	179	1,456
Thetso Gewog	58	496	Rubeysa Gewog	102	744
Lingbukha Gewog	31	250	Jena Gewog	64	616
Babesa Gewog	26	237	Thetso Gewog	13	96
-	-	-	Total	627	6,684

households and population of the villages/communities are presented in Fig. 3.8.2 and Table 3.8.1, respectively. The gewog-wise number of households and population are summarized in the table presented in the previous page.

(2) Present Rural Water Supply System

There are many villages which have the water supply systems constructed with the UNICEF's assistance. In the Study area, 31 UNICEF's schemes are found, and most of them are generally considered to be operated well though some stand pipes are found to be out of order. The system consists of stream or spring intake, transmission pipeline with valves, break pressure tank, clear water reservoir, distribution system, tapstands, and sedimentation tanks. In Bhutan, the UNICEF's contribution to the rural water supply is remarkable and successful, and its assistance services are found to be active. Their assistance were commenced in the period of Fourth Five Year plan (1977 - 1982), and about 1790 schemes have been completed so far under their assistance.

The present situation of water supply in each sub-area is described below.

1) Lobeysa Sub-area

The Lobeysa sub-area consisting of 21 villages/communities has a population of 3,086 and 177 households including schools and government offices. Out of these 21 villages/communities, 7 villages have schools and government offices. It is observed that only two (2) villages do not have any water supply system carrying their water from the existing springs and irrigation canals available near their houses. There are eight (8) water supply schemes funded by UNICEF, and 12 villages/communities are provided with the schemes of UNICEF. The other communities which are provided with water supply systems are considered to be government offices, and they have the systems constructed by their respective government organization such as MOA, MOI, RBA, GREF, etc. Most of the existing system takes the water source in the springs in and around the sub-area. The population of 2,729 equivalent to 88 % of the total population is at present served by the present water supply systems in the sub-area as summarized in the table.

Present Water Supply Situation in Lobeysa Sub-area

Item	Total	Served by Existing System	Percent
Population	3,086	2,729	88
Household	177	149	-
No. of Villages/Communities	21	19	-

2) Bajo Sub-area

There are eight (8) villages/communities in the Bajo sub-area, and only one (1), DSC/AMC, is considered to be a government office. Half of the villages/communities are considered to be left in the condition without any adequate water supply system, and the villagers have to take their water from existing irrigation canals running near their houses. Out of the total population of 983, only 353 persons which is equivalent to about 36 % are at present served by the existing water supply schemes. There are three (3) water supply schemes constructed under the assistance of UNICEF; Proper Bajo, Wangjokha and Matalumchu. The DSC/AMC offices are provided with the supply system constructed by MOA.

Present Water Supply Situation in Bajo Sub-area

Item	Total	Served by Existing System	Percent
Population	983	353	36
Household	115	40	-
No. of Villages/Communities	8	4	-

3) Phangyul Sub-area

18 villages are identified in the Phangyul sub-area, and total population and total number of household are estimated as 1,159 and 156 with the average population per household of 7.4 persons. Most of the villages are located on the high hilly lands along the valley of the Dang Chhu.

Nine (9) villages in the sub-area do not have any water supply system, and 745 persons are left without any supply system. There are seven (7) UNICEF schemes, and two (2) private schemes in the sub-area. Only 414 population is served by these existing supply schemes at present, and this value is considered equivalent to only 36 %.

Present Water Supply Situation in Phangyul Sub-area

Item	Total	Served by Existing System	Percent
Population	1,159	414	36
Household	156	57	-
No. of Villages/Communities	9	9	-

4) Rubeysa Sub-area

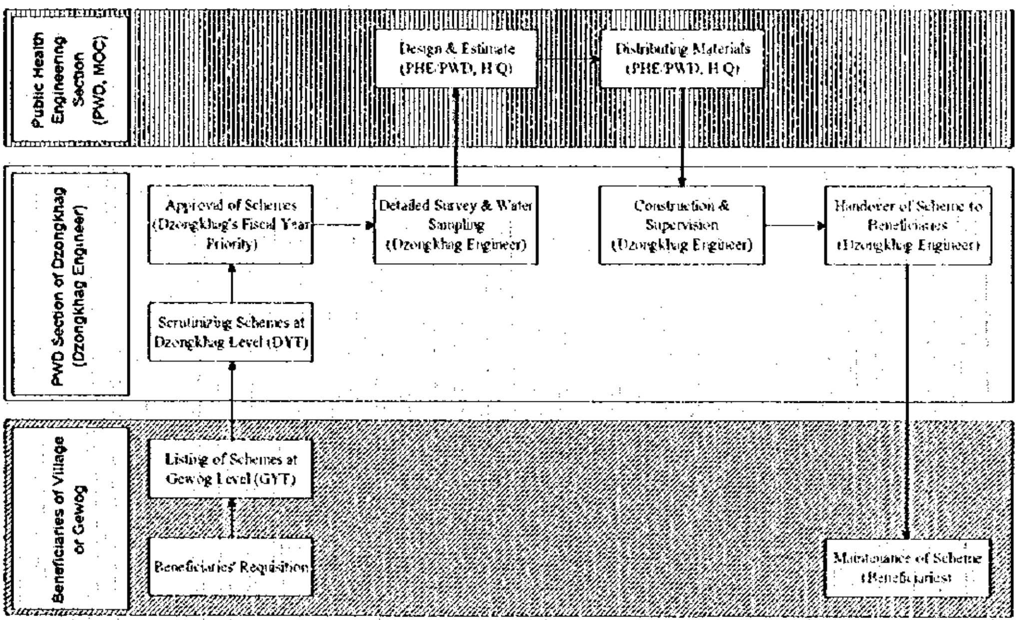
In the Rubeysa sub-area, there are 17 villages/communities identified, and out of them 13 villages are provided with the UNICEF's water supply scheme. As shown in the table, 1,006 of population is considered to be provided with proper water supply system out of the total population of 1,456.

Present Water Supply Situation in Rubeysa Sub-area

Item	Total	Served by Existing System	Percent
Population	1,456	1,006	69
Household	179	143	-
No. of Villages/Communities	17	13	-

(3) Present Operation and Maintenance of Water Supply System

The services of national level such as planning, etc. are taken up by the Public Health Engineering Section of PWD of MOC, while the Rural Water Supply & Sanitation Section of each Dzongkhag takes care of the implementation.



Note: GYT: Gewog Yargey Tshogchung
DYT: Dzongkhag Yargey Tshogchung

PROCEDURES TO IMPLEMENT RURAL WATER SUPPLY SCHEMES

The above figure schematically presents the procedures to implement the rural water supply schemes. The beneficiaries consisting of more than five (5) households present their requisition for the necessary water supply system, and such requisitions are scrutinized by the Dzongkhag Engineer for selecting and prioritizing of water supply. The detailed survey and sampling of the raw water are conducted by the Dzongkhag Engineer. The results of such survey are transferred to the Public Health Engineering Section of PWD in MOC Head Quarter for further detailed design and cost estimate. The procurement and delivery of the necessary materials are controlled by PHE/PWD of MOC Head Quarters. The construction of the supply system is conducted under the supervision of the Dzongkhag Engineer with the materials delivered at the site. The common labors necessary for the construction works have to be prepared by the beneficiaries themselves. After the completion of the construction, the system is handed over to the beneficiaries for the operation by them. The operation and maintenance of the water supply system handed over have to be conducted by the beneficiaries themselves under the supervision of the Dzongkhag Engineer.

CHAPTER 3
TABLES

Table 3.8.1 Identified Villages/Communities in the Study Area

Lobeysa Sub-area			Bajo Sub-area			Phangyul Sub-area			Rubeysa Sub-area		
	Present Population			Present Population			Present Population			Present Population	
Village/Community	Household	Population	Village/Community	Household	Population	Village/Community	Household	Population	Village/Community	Household	Population
BABESA GEWOG			THETSO GEWOG			PHANGYUL GEWOG			RUBEYSA GEWOG		
1 Mitshina	18	250	1 Proper Bajo	33	251	1 Proper Phangyul	24	188	1 Nyizergang Gompa	20	156
2 Sopsokha	9	70	2 Bajothang	5	61	2 Phangyul Gompa	2	5	2 Rumina	19	123
3 Yuwakha	15	85	3 DSC/AMC	1	50	3 Jemkhelo	1	6	3 Nyalakha	10	74
4 Chimi Lhakhang	1	105	4 Thangu	11	59	4 Yangcheytawa	1	5	4 Ruteokha	16	107
5 Gomji	2	20	5 Matalumchu	8	75	5 Chumey Gompa	4	45	5 Tshemcho	9	59
6 Baywokha	5	40	Sub-total	58	496	6 Chungsekha	26	175	6 Jasukha	5	45
7 Yusakha	13	105	LINGBUKHA GEWOG			7 Domkhar	14	123	7 Awakha	3	22
8 Pachekha	2	25	6 Umtekha	31	250	8 Paropselsa	1	9	8 Maphekha	8	71
9 Jangsapo	4	49	Sub-total	31	250	9 Vegopara	1	5	9 Umtekha	4	33
10 Tshokona	12	80	BABESA GEWOG			10 Rabuna inc. PWD	4	70	10 Nyegapara	7	45
11 NRTI***	1	630	7 Wangjokha	14	177	11 Geonkhar	27	192	11 Tashidingkha	1	9
12 Gangkha	8	41	8 Matalumchu	12	60	12 Lenkhena	1	5	Sub-total	102	744
13 Power Station	1	30	Sub-total	26	237	13 Omchuphunasa	1	22	JENA GEWOG		
14 Pry School***	1	510				14 Kumchi	21	146	12 Balakha	7	56
15 Jamripang	9	100				15 Damina	1	10	13 Themakha	37	319
16 PWD Camp (Maint.)	19	100				16 Ribana	19	92	14 Phuntshogang	9	100
17 Motokha	2	18				17 Pachekha	1	12	15 Tashi Tokha	11	141
18 Pangnang	10	65				18 Chuzomsa	7	49	Sub-total	64	616
19 PWD Camp (Const.)	1	75							THETSO GEWOG		
20 RBA Firing Range**	1	206							16 Nyechegeykha	10	68
Sub-total	134	2,604							17 Nalabji	3	28
THETSO GEWOG									Sub-total	13	96
21 Rinchengang	43	482									
Sub-total	43	482									
Total	177	3,086	Total	115	983	Total	156	1,159	Total	179	1,456
									Total Household and Population in the Study Area:	627	6684

Note: The population and household in the Wangduephodrang Town area are discussed in the sub-sections for the urban water supply plan.

CHAPTER 3
FIGURES

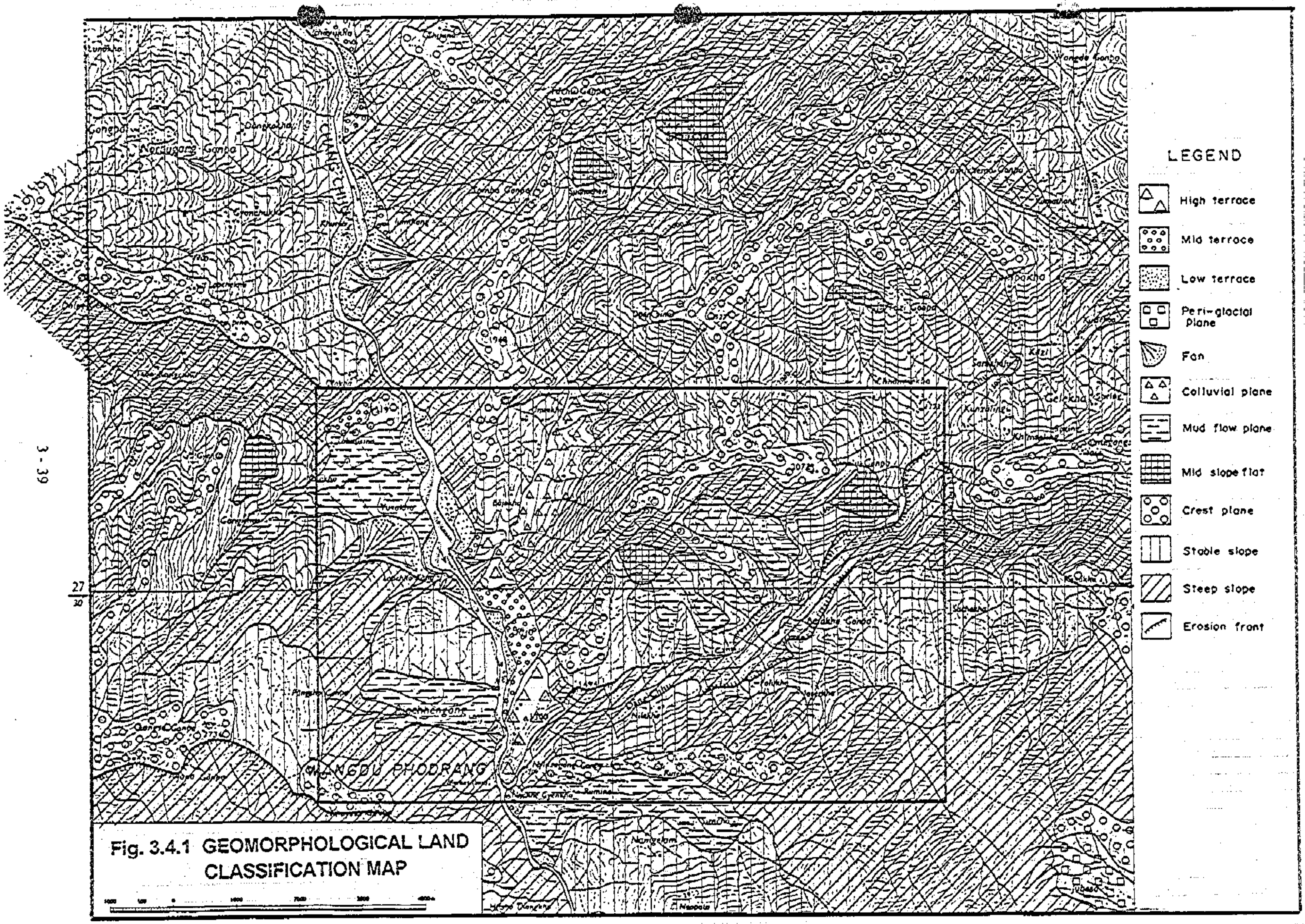
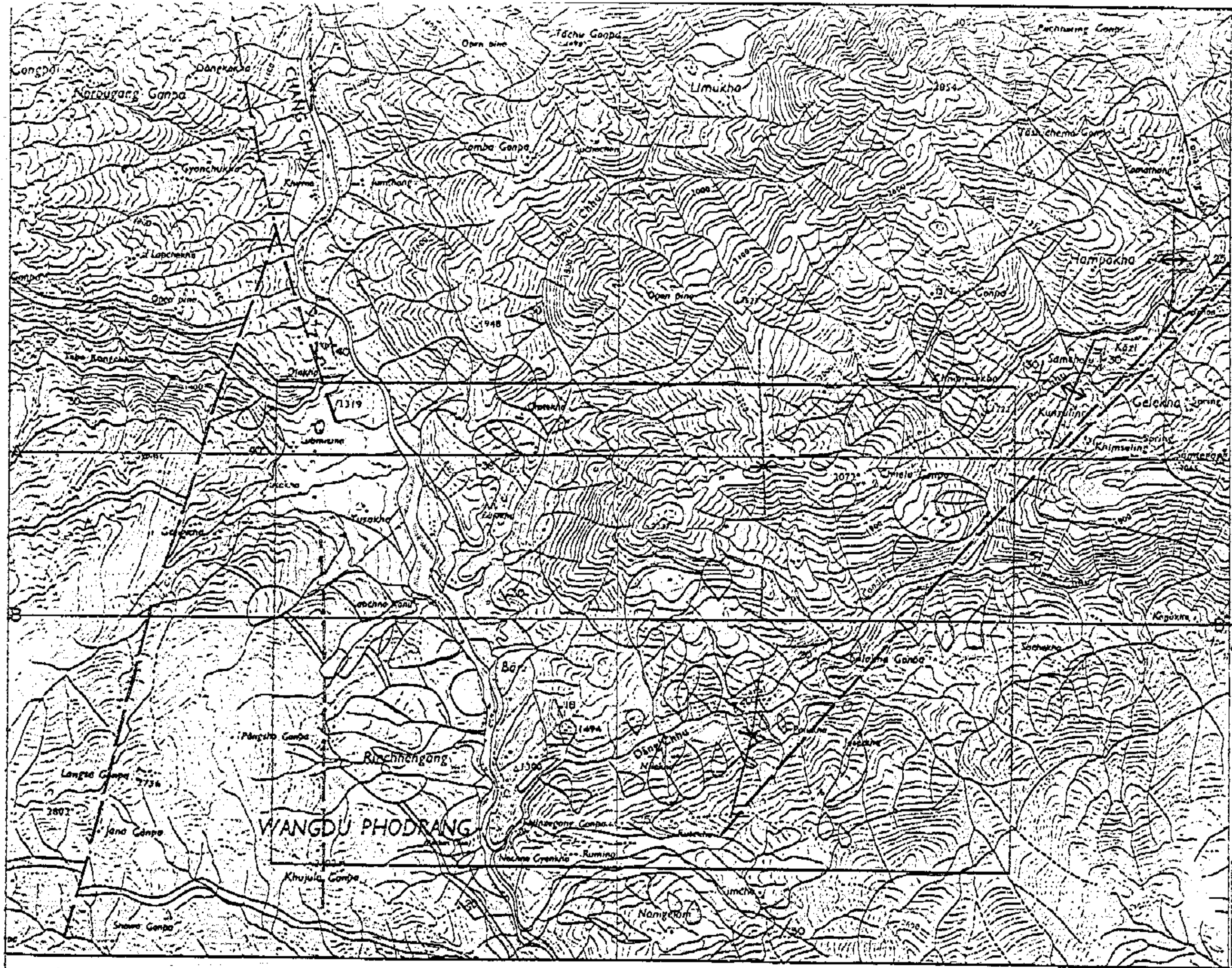


Fig. 3.4.1 GEOMORPHOLOGICAL LAND CLASSIFICATION MAP



LEGEND

- High Terrace
- Mid. Terrace
- Low Terrace
- Fan
- Colluvium
- Younger mud Flow
- Older mud flow
- Slided block
- Thimphu Series
  - Gneiss
  - Schist
- Polo Series
  - Lime stone
  - Schalstein
  - Quartzose member
  - Schist
- Granite
- Fault
- Anticline
- Syncline
- Beding plane
- A~A', B~B' Profile line

ROYAL GOVERNMENT OF BHUTAN

THE STUDY ON GROUNDWATER DEVELOPMENT PROJECT IN WANGDUEPHODRANG DISTRICT

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 3.4.2 GEOLOGICAL MAP

1 : 50,000

1000 500 0 1000 2000 3000 4000m

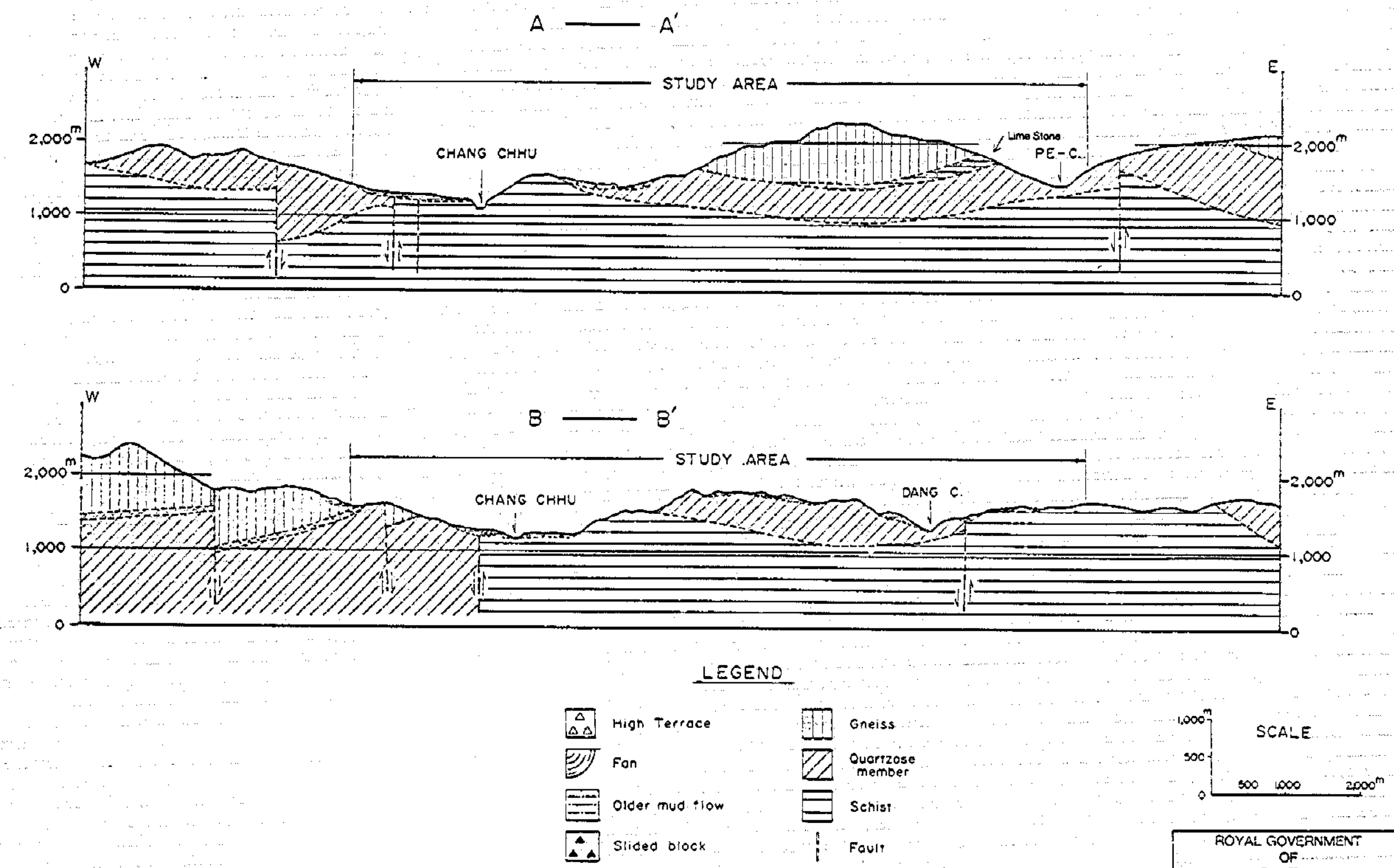


Fig. 3.4.3 GEOLOGICAL PROFILE

ROYAL GOVERNMENT OF BHUTAN
THE STUDY ON GROUNDWATER DEVELOPMENT PROJECT IN WANGDUEPHODRANG DISTRICT
JAPAN INTERNATIONAL COOPERATION AGENCY

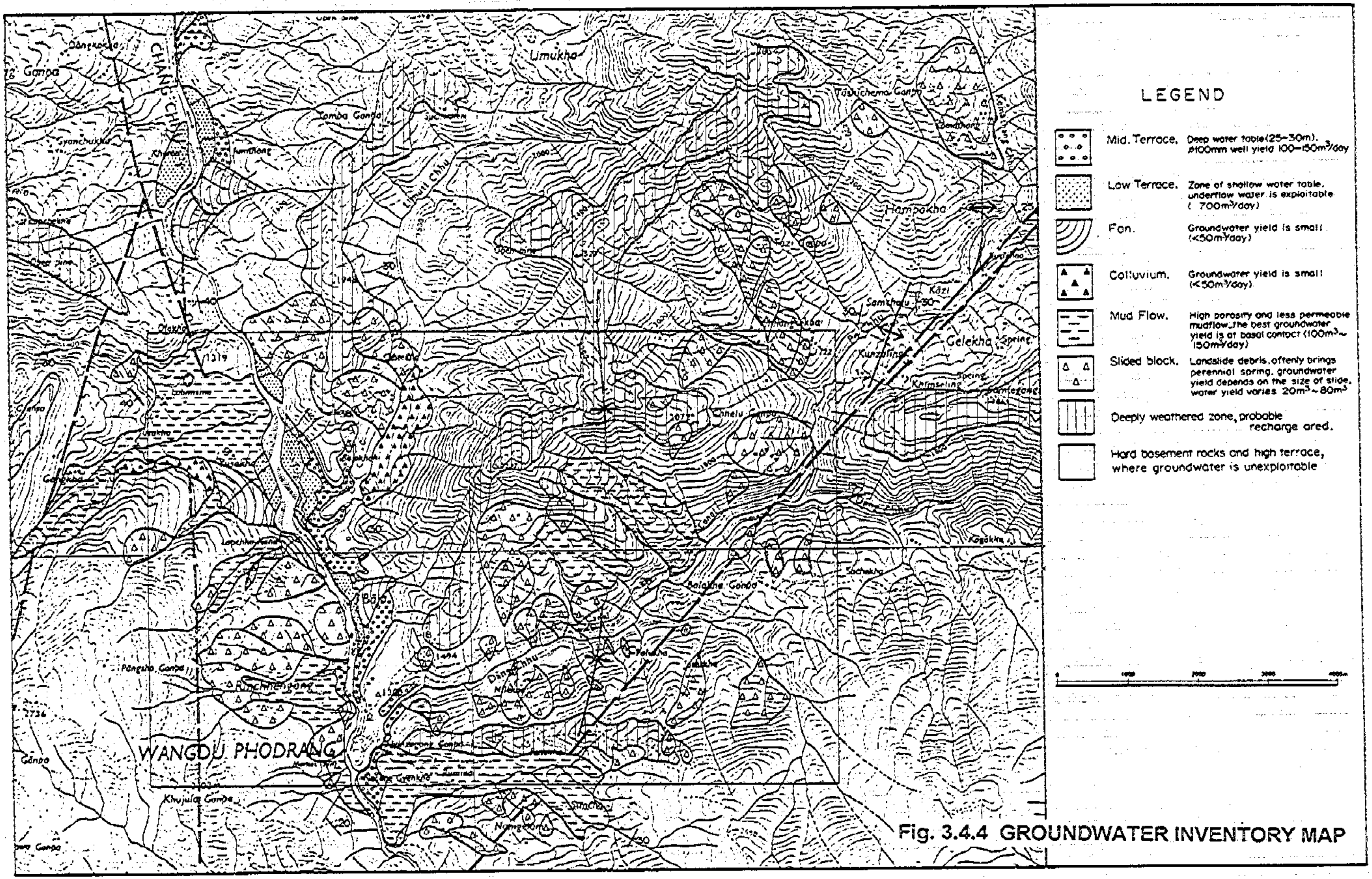


Fig. 3.4.4 GROUNDWATER INVENTORY MAP

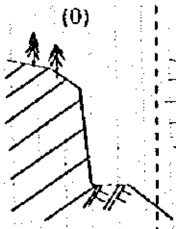
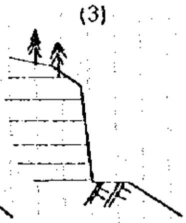
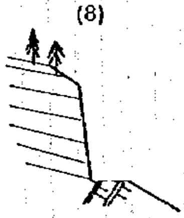
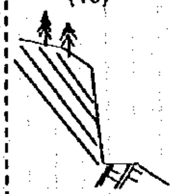
Attribute	Description/ measurement				
Vegetation		tough root anchoring (-3)	thick (0)	moderate (3)	sparce, barren cultivated (5)
Slope Angle (degrees) up		< 5 (0)	6 ~ 20 (3)	21 ~ 45 (5)	> 45 (3)
Slope Angle (degrees) down		< 5 (0)	6 ~ 20 (5)	21 ~ 30 (8)	> 31 (10)
Nearby drainage	none (0)	simple  (3)	under cutting or rill swarm  (5)	gully  (8)	active gully  (10)
Slope surface		smooth (0)	un-even (3)	mound scattered (4)	irregular with mid-slope flat (5)
Surface cover thickness		< 3 m (0)	3 ~ 5 m (3)	5 ~ 10 m (5)	> 10 m (3)
Surface cover material		massive debris, soil (3)	colluvium, debris with < 1 m block (5)	debris w/ wet mud or 3 m block (8)	loose debris, rock debris (10)
Bed rock	massive resistant (0)	jointed hard R massive soft R (3)	not observed & others (5)	Weatherd R open-cracked, foliated (8)	crushed, decomposed, argillized (10)
Orientation of discontinuity	(0) 	nearly flat (3) 	not clear (5) 	5 ° ~ 20 ° (8) 	> 20 ° (10) 
Cutting + banking height		< 3 m (0)		3 ~ 6 m (3)	> 6 m (5)
Deformation of structure	none (0)	minor < 3 m (3)	med., deform. 3 ~ 6 m (5)	med. ~ major deform. repaired temporarily (8)	down warp seems active (10)
Possible wash out/ rock fall		not likely (0)	possible (3)	probable (4)	in danger (5)
Existing slide, creep failure (w < 6 m)	none (0)	rill erosion (3)	old slide near-by (< 10 years) (5)	new slide within 20 m (8)	zone of major or active slide (10)

Fig. 3.4.5 SCORE FOR RATING VULNERABILITY

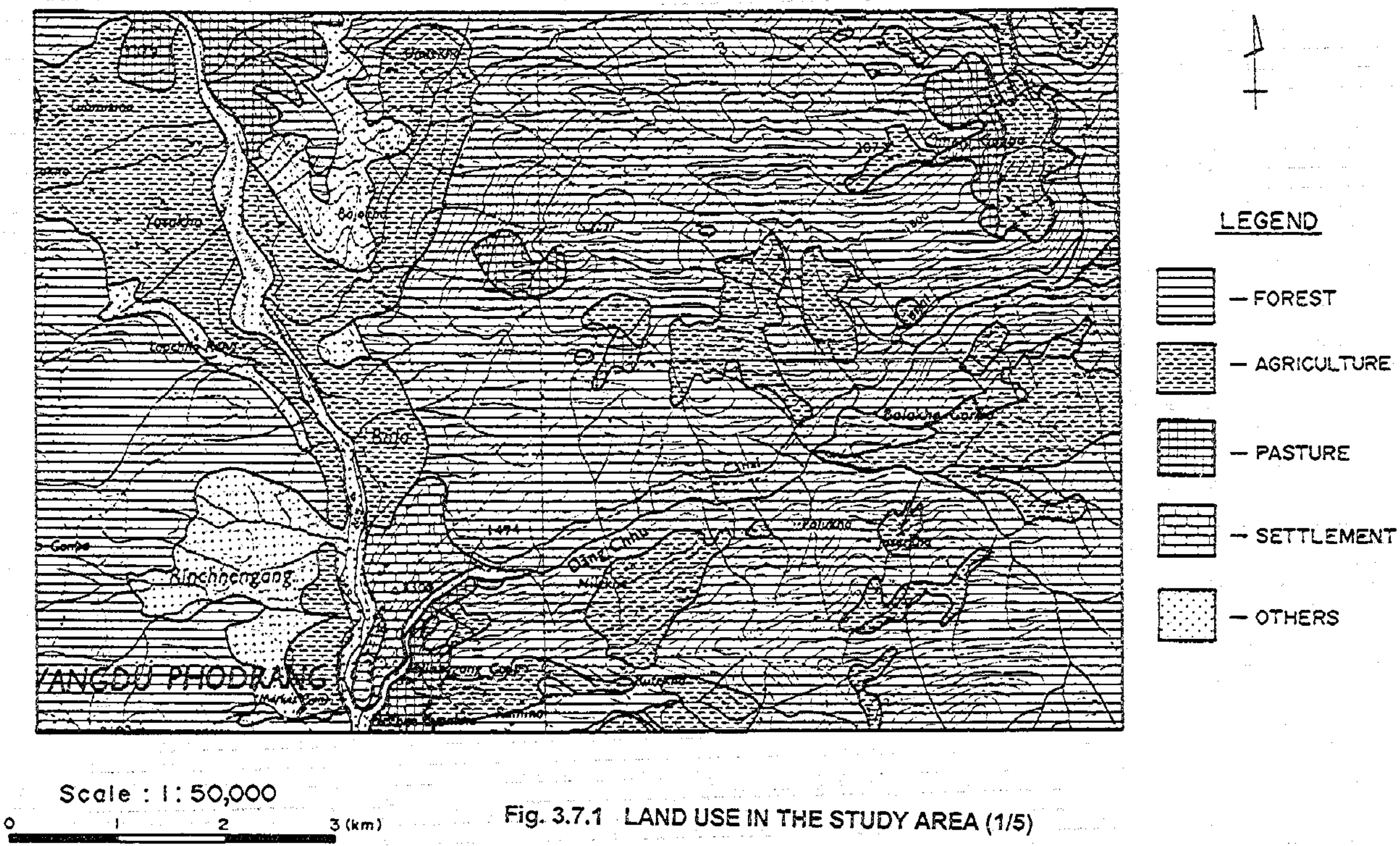


Fig. 3.7.1 LAND USE IN THE STUDY AREA (1/5)

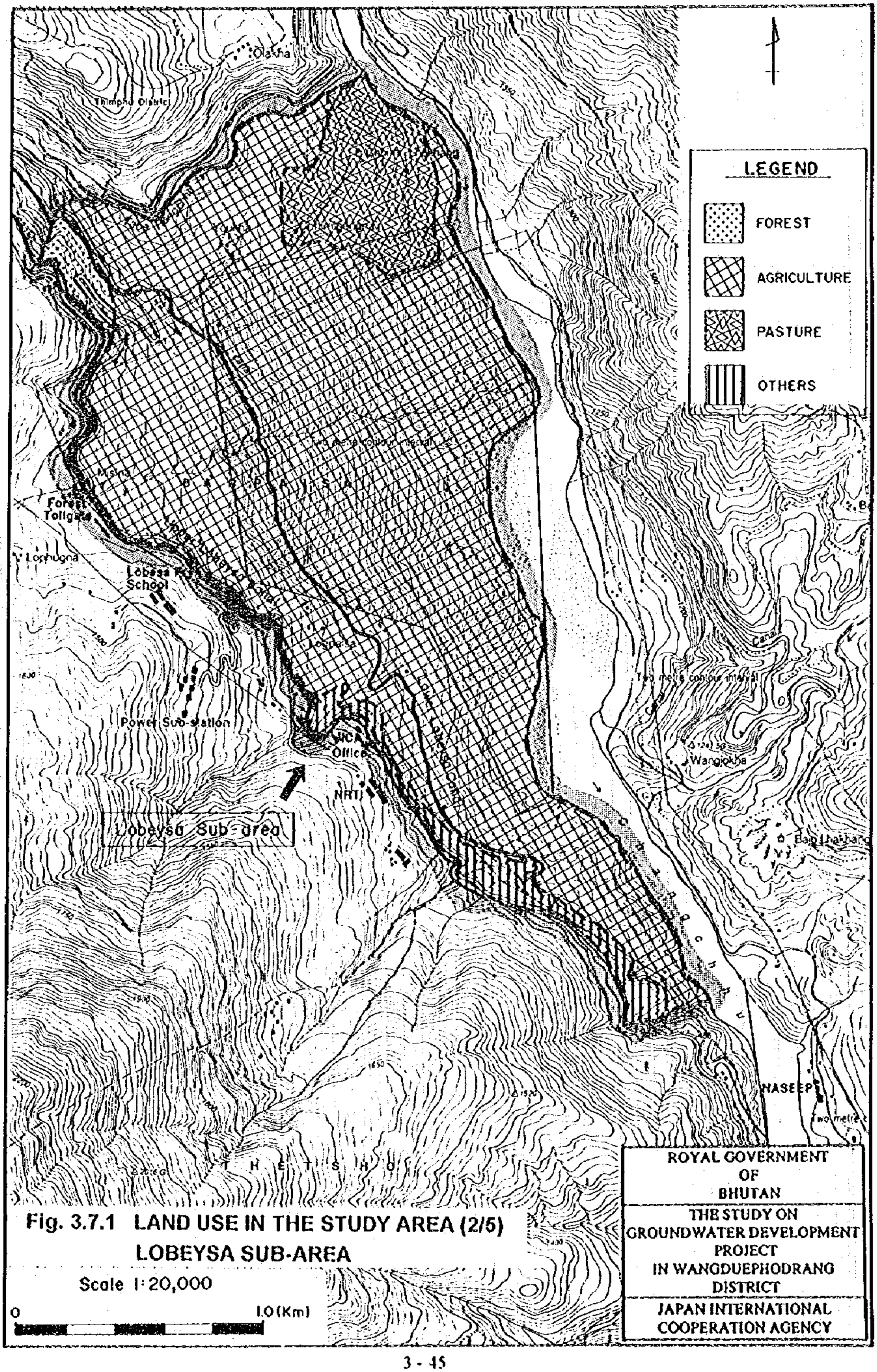


Fig. 3.7.1 LAND USE IN THE STUDY AREA (2/5)
LOBEYSA SUB-AREA

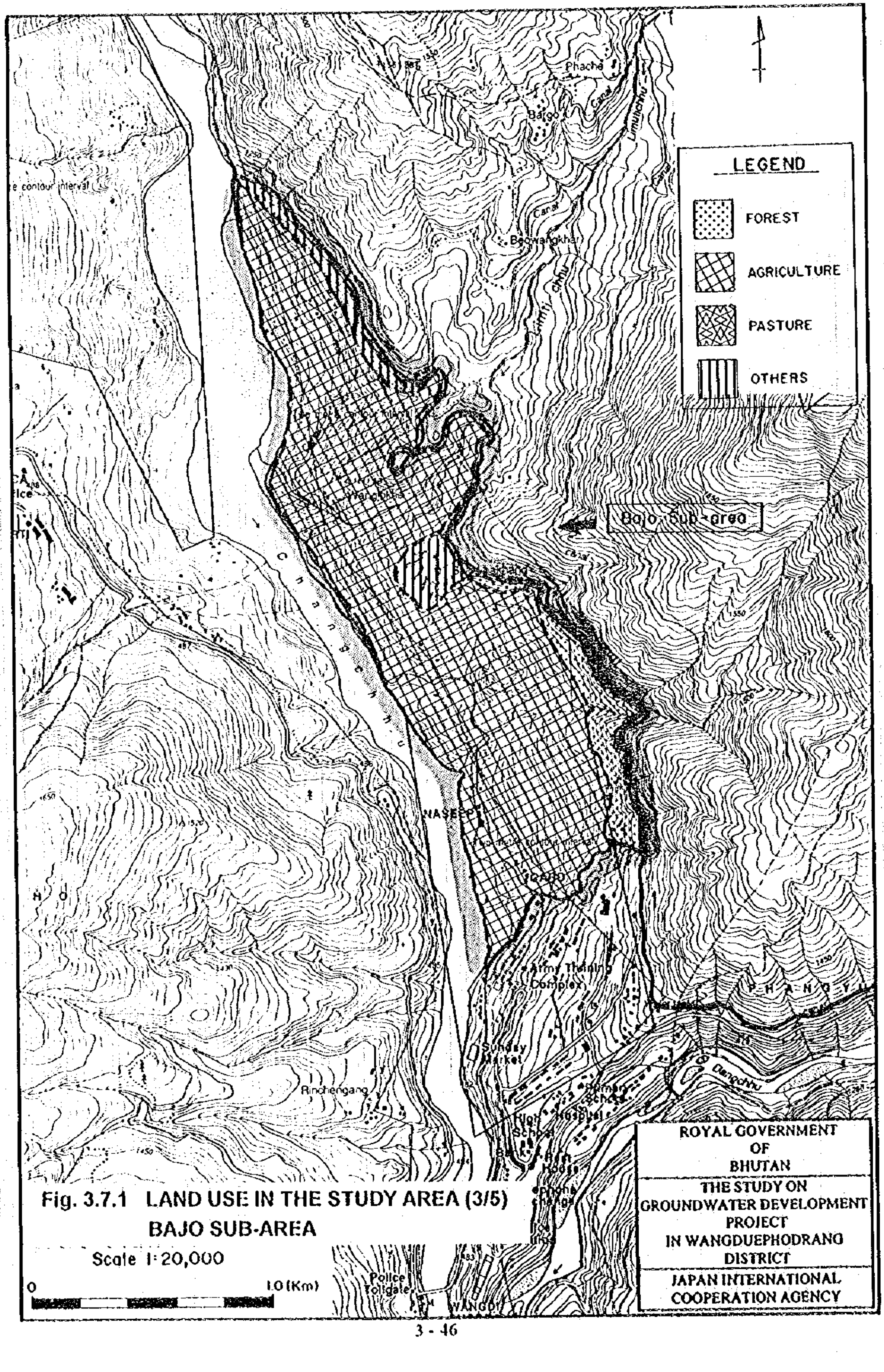


Fig. 3.7.1 LAND USE IN THE STUDY AREA (3/5)
BAJO SUB-AREA

ROYAL GOVERNMENT OF BHUTAN
THE STUDY ON GROUNDWATER DEVELOPMENT PROJECT IN WANGDUEPHODRANG DISTRICT
JAPAN INTERNATIONAL COOPERATION AGENCY

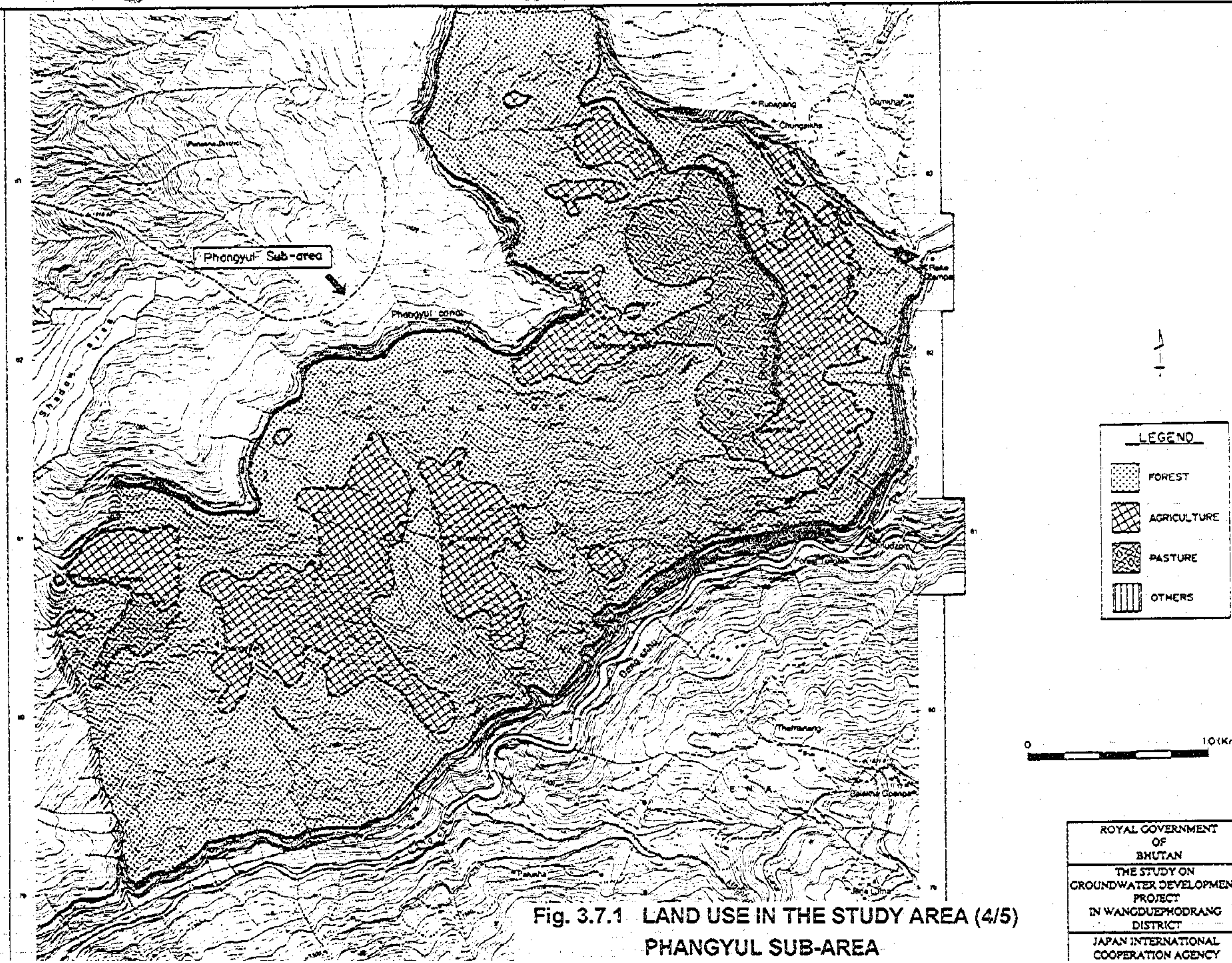


Fig. 3.7.1 LAND USE IN THE STUDY AREA (4/5)
PHANGYUL SUB-AREA

ROYAL GOVERNMENT OF BHUTAN

THE STUDY ON GROUNDWATER DEVELOPMENT PROJECT IN WANGDUEPHODRANG DISTRICT

JAPAN INTERNATIONAL COOPERATION AGENCY

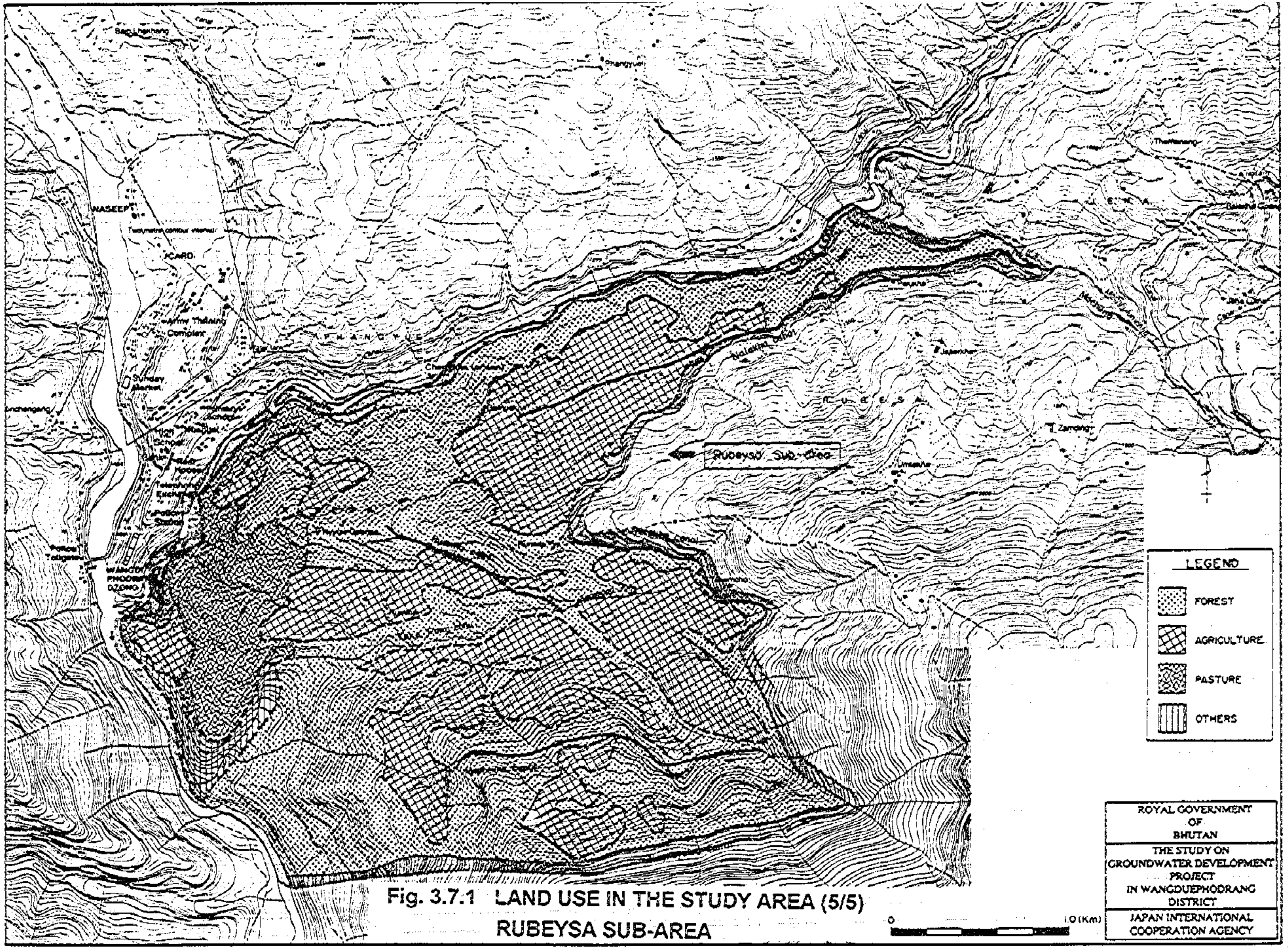
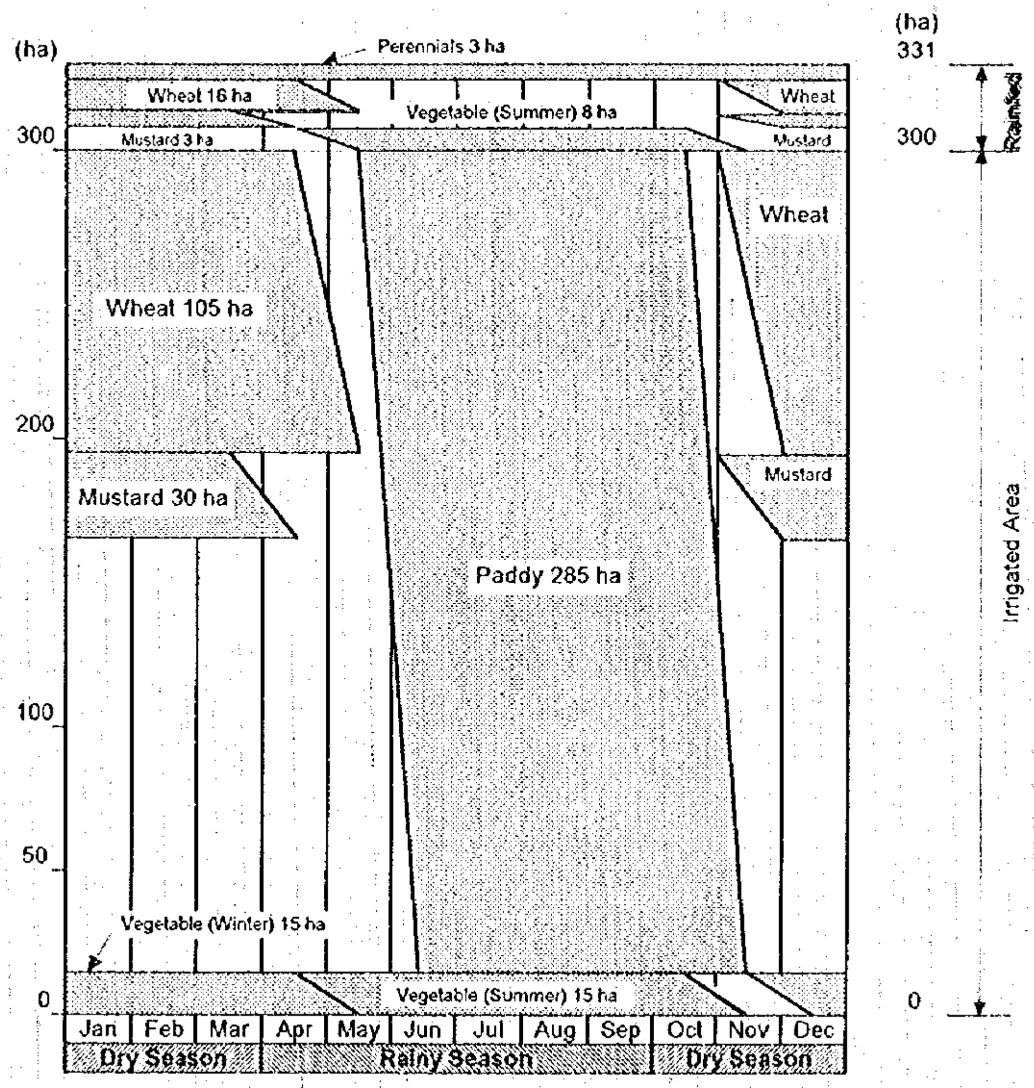
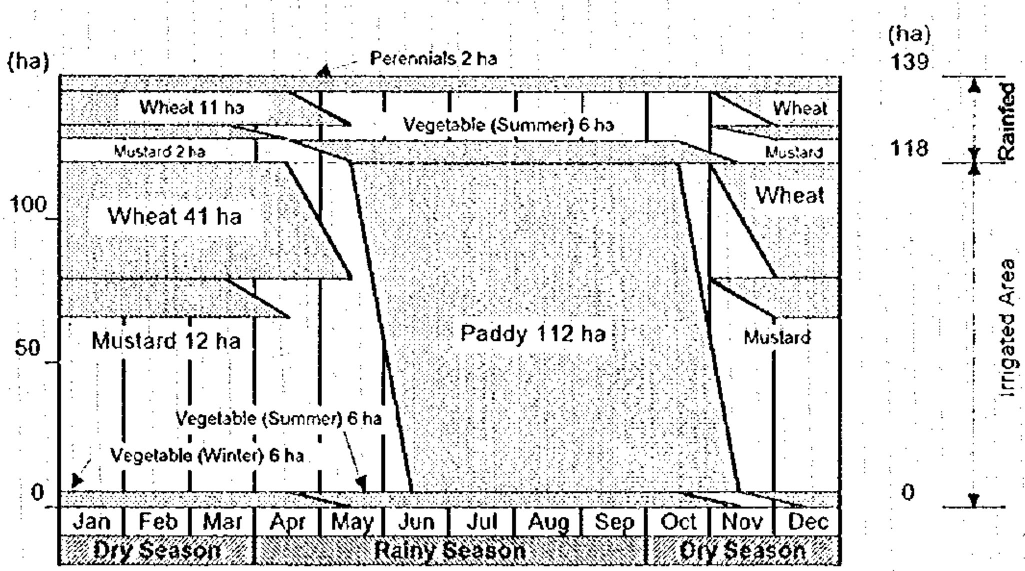


Fig. 3.7.1 LAND USE IN THE STUDY AREA (5/5)
RUBEYSA SUB-AREA

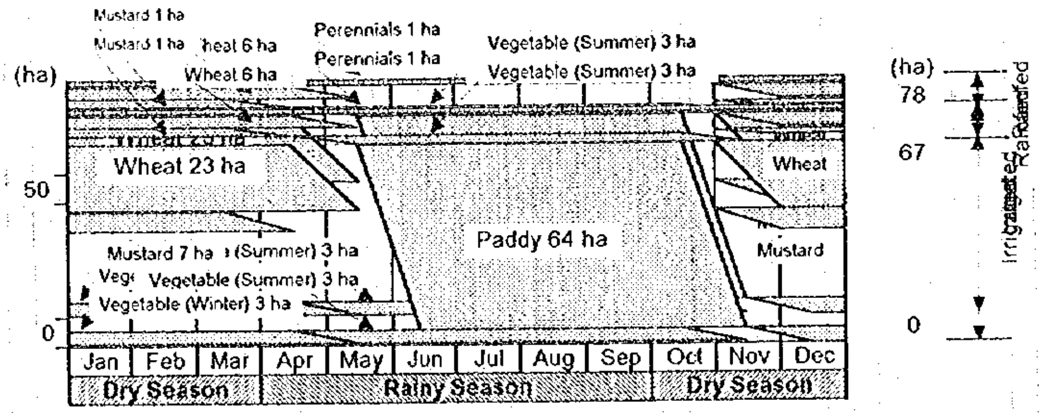


Lobeysa Sub-area

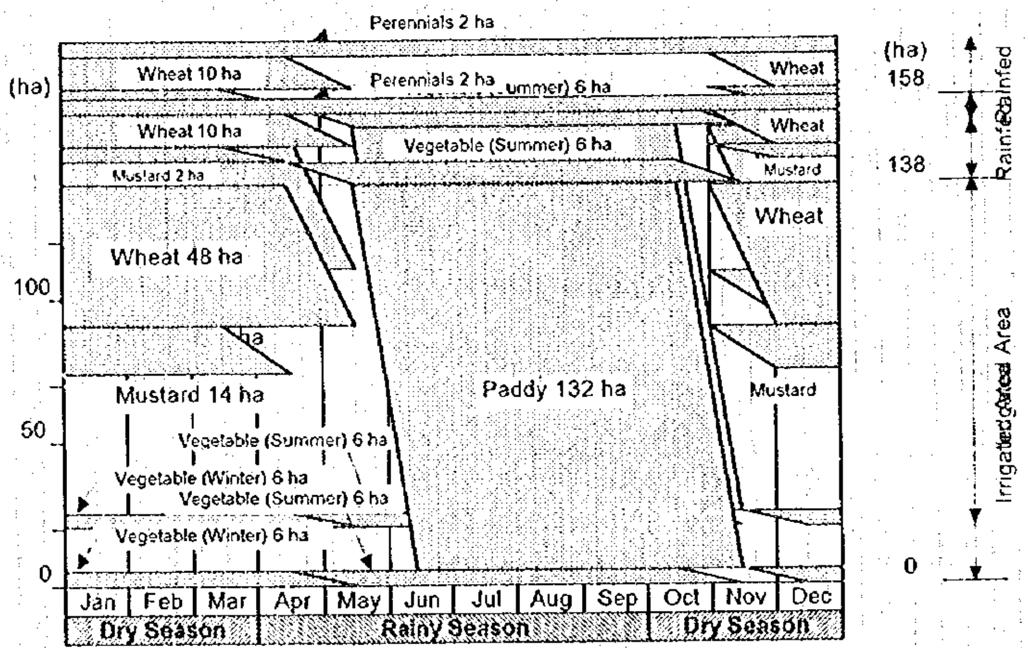


Bajo Sub-Area

Fig. 3.7.2 Present Cropping Pattern (1/2)



Phangyul Sub-Area



Rubeysa Sub-Area

Fig. 3.7.2 Present Cropping Pattern (2/2)

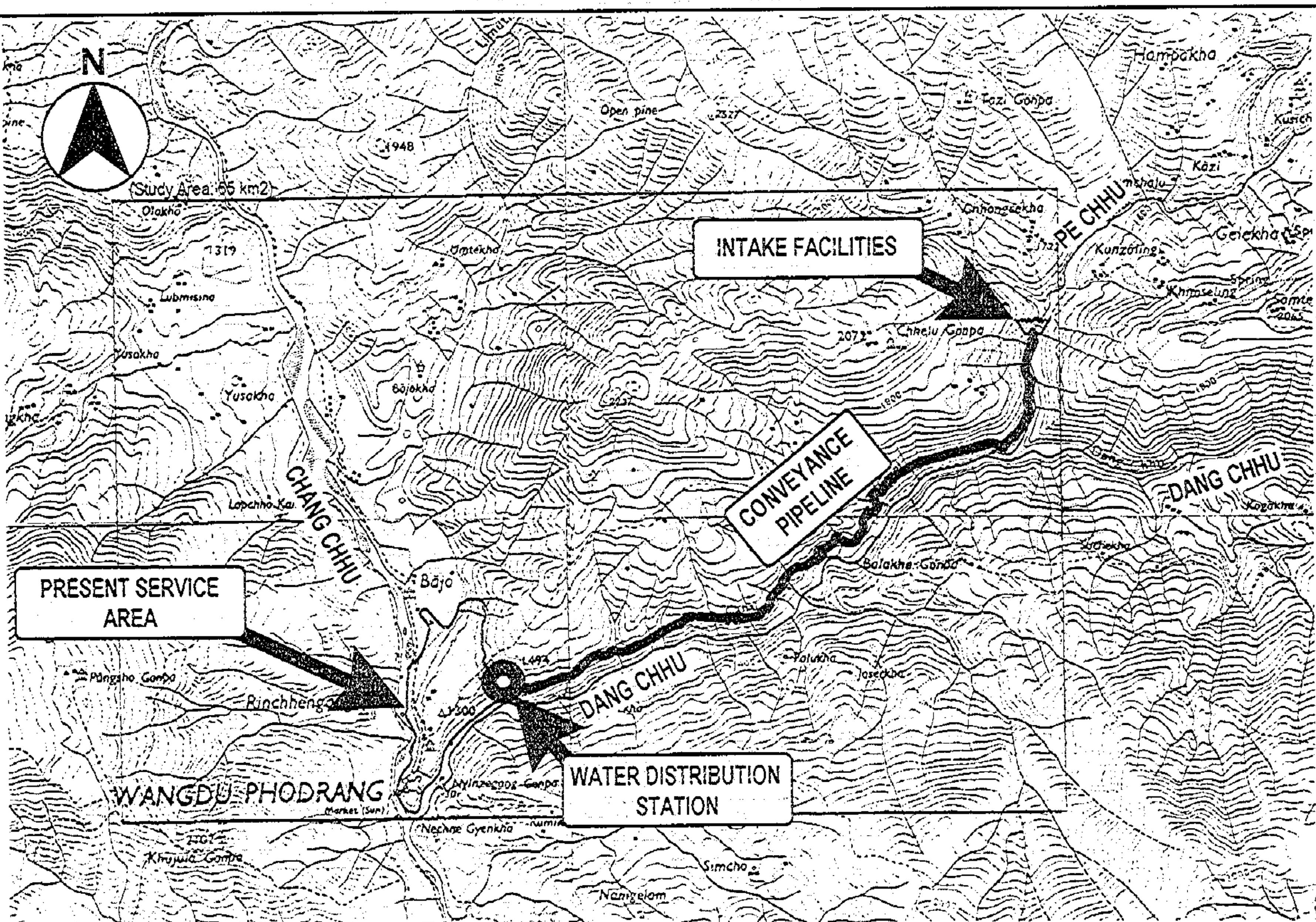


Fig. 3.8.1 EXISTING URBAN WATER SUPPLY SYSTEM FOR WANGDUEPHODRANG TOWN AREA

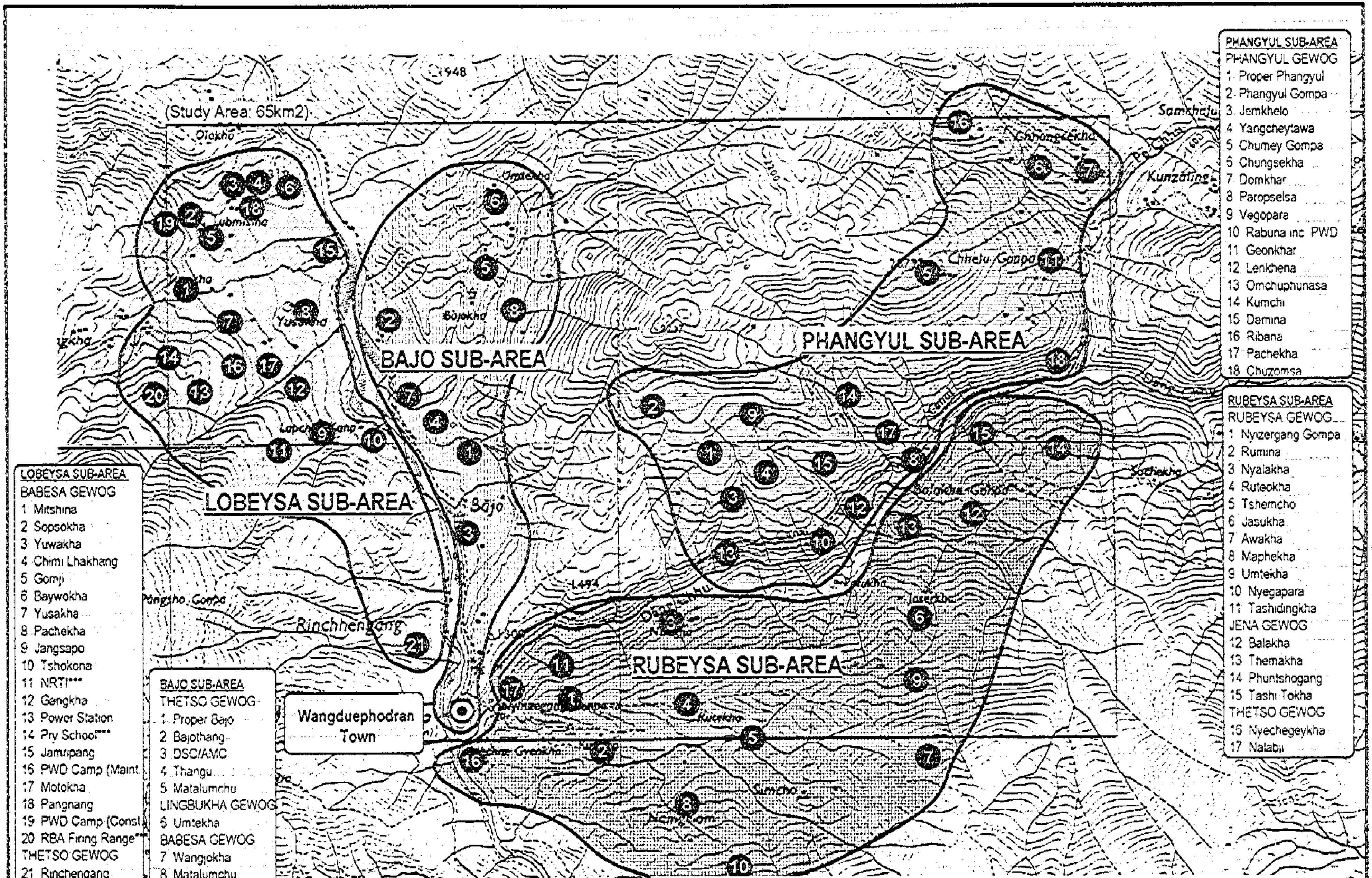


Fig. 3.8.2 LOCATION OF THE IDENTIFIED VILLAGES/COMMUNITES

CHAPTER 4
WATER RESOURCES POTENTIAL

4. WATER RESOURCES POTENTIAL

4.1 Outline of Present Water Use

The following four (4) categories of water resources are available in the Study area.

- Surface water flowing in the perennial and seasonal rivers and streams.
- Sub-surface water flowing in the gravel zones underneath of or near by rivers.
- Groundwater available in the river terrace deposit.
- Spring water stored in the land slide blocks in the hilly areas.

Among them, the spring water and the stream flow originating from the spring are at present utilized for irrigation and domestic water supply purposes. No other purposes of utilization such as industrial purpose are not identified in the Study area at present, and such other purposes are neither planned nor scheduled in the future according to the Dzongkhag Administration.

(1) Lobeysa Sub-area

In Lobeysa Sub-area, the irrigation water is supplied by the river water of the Tabe Rongchhu through the existing Upper and Lower Lobeysa Canals. The rural water supply by schemes constructed by the Dzongkhag under the UNICEF's assistance contribute for the supply of safe water in this sub-area. The UNICEF's schemes take the water from the spring near the villages, and the other water supply systems of the government also take their water from the springs.

(2) Bajo Sub-area

The irrigation water is taken from the Pe Chhu through the existing Bajo canal. The surface water of the Pe Chhu is used for the urban water supply for the Wangduephodrang town area as well. The water supply in this sub-area depends mainly on the spring source in the hilly area. Villagers who do not have any adequate supply system have to take the water from the Chang Chhu or irrigation canals for their domestic and drinking purposes at present.

(3) Phangyul Sub-area

There are some irrigation canals to supply irrigation water in the Phangyul Sub-area, and these canals originate from the perennial streams located at higher hilly areas. The rural water supply schemes are also identified as UNICEF's scheme. Such schemes have the water from the nearby springs. The villagers having no scheme take the water from the small seasonal streams or the pools formed beside small springs.

(4) Rubeysa Sub-area

There area some UNICEF schemes in the sub-area, which utilize spring water. The irrigation water is supplied through some irrigation canals in the area taking the water from some perennial springs flowing along the steep valleys in the hilly areas.

4.2 Experimental Facilities

4.2.1 General

(1) Objective and Concepts

The experimental facilities were constructed to study on the appropriate development measures of the water resources which include groundwater, spring water, sub-surface water and river water. The most appropriate development measures of water resources have been studied and evaluated through the construction, operation/maintenance and monitoring of these experimental facilities. It is certain that the experience gained by this study would help to establish the adaptable and sustainable water resources development systems as well as their wide utilization in similar areas in Bhutan.

During the field survey period, a series of field reconnaissance surveys were carried out to examine the construction conditions and to confirm the willingness of the government staff as well as the local people. Based on the results of such field reconnaissance survey, the proposed experimental facilities were selected among the various alternatives putting emphases on the following considerations.

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

(2) Proposed Scheme

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

- Groundwater scheme
- Spring water scheme
- Sub-surface water scheme
- River water scheme

All of them are considered important and essential to mitigate the constraints of the present water utilization in the area. Therefore, it is proposed to select the facilities so as to represent each kind of water source, and it is necessary to consider the sustainability of these facilities.

The experimental facilities were constructed in four (4) months period from November, 1994 to March 1995 by a local contractor under the supervision of the Study Team. After the completion of their construction, monitoring works were carried out to collect the necessary data and information for confirming and examining their adaptability, applicability, sustainability and functionability as well as establishing the most appropriate development measures.

The locations of the facilities are presented in Fig. 4.2.1.

(3) Monitoring Works

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

The items presented in Fig. 4.2.2 were monitored. The monitoring formation described below was applied, and whole of the works were carried out satisfactorily during the survey period.

1) Formation of Monitoring Works

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

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

As for the spring water storage facility (spring water scheme) in the Phangyul sub-area and the shallow well pumping facility (sub-surface water scheme) in the Bajo sub-area, it was considered possible to operate such facilities with a certain skill as well as to monitor their performance. The routine monitoring works was, therefore, conducted by local people to mitigate the work loads to the limited numbers of government staff as well as to facilitate the demonstration effects of the facilities.

The meteorological records required for monitoring were collected and compiled by the counterpart staff in RNRRC office. In order to ensure the observation works, the observation works was carried out by RNRRC staff and local people at each site of experimental facility under the management and control of the project's counterpart staff who had participated in the Study on experimental facilities since the initial stage. The observation data was recorded in the monitoring record books attached to each experimental facility whenever such monitoring works were done. The formation of the above monitoring system is illustrated in Fig. 4.2.3.