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Soil Survey Unit (SSU)
National Soil Services Centre, Simtokha
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TECHNICAL REPORT ON THE SEMI-DETAILED SOIL SURVEY OF THE ARABLE LANDS OF PUNHAKA DZONGKHAG (Puna Tsang Chhu)

Report No. 9

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SUMMARY

This is the technical report of the semi-detailed soil survey of the main areas of arable lands of Punakha Dzongkhag. The fieldwork was done between January 1999 to March 2000.

The data were used as a major training exercise during the design and development of the Bhutan Soil Databank (BHUSOD) leading to the long delay between completion of the survey and production of this report.

The survey area covers 69 km^2 (about 17000 acres). The soils were examined a almost 1300 sites, almost 200 of which were profiles that were fully described and sampled for laboratory analysis.

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The fieldwork for this survey was done by Kado Tshering, Tsheten Dorji, H B Tamang and Tshering Dorji. Kado Tshering coordinated the field activities and was responsible for the logistic arrangements. Ian Baillie coordinated the technical aspects of soil classification and mapping, and land evaluation. The report was drafted by Tshering Dorji, Kado Tshering and Ian Baillie and compiled by Ms Pema Wangmo. The soil analyses were done by SPAL. The interim map was prepared by Kado Tshering and *. The final GIS map will eventually be done on the SSU Geographic Information System.

We are grateful to the Dasho Dzongda and the dzongkhag staff of Punakha, particularly DAO Sonam?** and and senior extension agent **. We are also grateful to the **, EA Norbugang, *, EA *Tsirigang), * EA Shengana, and *** , for their logistic assistance and hospitality during our fieldwork.*

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PLACE NAME SPELLINGS

The spelling of Bhutanese place names in English is still in a state of transition. For Dzongkhag and gewog names we have used the versions issued by the Dzongkha Development Commission (DDC 1998). The spellings of most villages are those on the 1998 1:25 000 topographic maps issued by Survey of Bhutan (SoB). However we have substituted a few other names where these are consistently used by local people and differ significantly from the SoB maps.

ABBREVIATIONS AND GLOSSARY

(Simple metric units and chemical element symbols not included)

AAS	Atomic absorption spectrophotometery
Acre	Area of measurement, = 0.405 ha
Alluvial fan	Poorly stratified and sorted material deposited on floor of side valley
AmOAc	Ammonium acetate (extractant for exchangeable cations and for measuring CEC)
asl	Above sea level
ASP	Aluminium Saturation Percentage
AvP, AP	Available Phosphate
AWC	Available water capacity (amount of water held in soil at suctions low enough for root uptake, = MC% FC – MC% WP)
BHUSOD	Bhutan Soil Databank
SSU	Bhutan Soil Survey
BS%	Base saturation percentage
C	Clay (finest mineral particles in soils, > 2um in diameter, important store for some nutrients and water, make soils sticky & heavy to work)
ca	Approximately
CEC	Cation exchange capacity
CL	Clay loam
cm	Centimetre
Colluvium	Local hillwash, moved by surface erosion and slow non-glacial creep processes.
Complex	Soil mapping unit with several co-equal soil classes
Concave	Slope form of dip on slope, with steep gradient upslope and gentle gradient downslope. Tends to accumulate water & be imperfectly or poorly drained.
Consociation	Soil mapping unit with one soil class dominant but others as minor constituents
Convex	Slope form of protuberance on slope, with gentle gradient upslope and steep gradient downslope. Tends to shed water & be droughty.
CORE	Council of Research and Extension
Creep	Slow gravitational mass movement of colluvium downslope.
Crotovina	see 'krotovina'
Ccv	Concave
Cvx	Convex
Danida	Danish International Development Assistance.
DBMS	Database management system (Database)
EBS%	Effective base saturation (= TEB/ECEC)
EC	Electrical conductivity
ECEC	Effective cation exchange capacity (=TEB + Extr Al + Extr H)
Eluvial	Soil horizon formed by the washing out of some components
ET	Evapotranspiration
Evapotranspiration	Sum of evaporation from soil and other surfaces, and transpiration from leaves
Exch	Exchangeable (for cations)
Extr	Extractable (for soil nutrients)
FC	Field capacity (MC% at suction of 0.1 atmospheres)
Fine earth	Soil particle size < 2mm

FeMn	Ferri-manganiferous, dark red - reddish brown - black stains and soft concretions with high contents of ferric iron and manganese in horizons with seasonally impeded drainage
Freely drained	Soils in which most large pores drain their water soon after rain or irrigation at all times of the year. Identified by moist or dry feel, and warm brown, reddish or yellowish colours and absence or grey, rust or orange mottles
FYM	Farmyard manure
GIS	Geographical information system
Gley	Soil that is permanently wet, poorly aerated and has predominantly greyish colours, due to reduction of free iron to ferrous valency state. May have local oxidising conditions giving rust - coloured mottles, especially around root channels.
GLCE	General land capability evaluation
GPS	Global positioning system
GSI	Geological Survey of India
ha	Hectare
HCl	Hydrochloric acid
Horizon	Soil layer
Illuvial	Soil horizon formed by enrichment of some components washed in from eluvial horizon(s) above
ID	Imperfectly drained (soil)
Imperfectly drained	Soils in which most large pores drain their water soon after rain or irrigation for much of the year, but remain filled for long spells in summer. Identified by moist or wet feel, and grey or brown colours and many grey, rust or orange mottles.
In situ	In original position or place (Latin)
Interfluve	Land between two rivers, include halves of two valleys and ridge between them, (from Latin inter = between, fluvius = river)
Kamzhing, Kamshing	Rainfed agriculture
Knickpoint	Steep section in long profile of river bed, separating 2 concave sections
L	Loam (Mixed soil with substantial quantities of all three particle size classes, i.e. clay, silt and sand)
Lamella (pl. = –ae)	Discontinuous horizontal subsoil layer or lens of deposited silt or clay (usually from deposition of parent material, not argilluviation)
LS	Land Suitability
MD / MWD	Moderately well drained (soil)
MC%	Moisture content % (w/w)
MoA	Ministry of Agriculture
MLU	Miscellaneous Land Unit
Munsell	System of standard soil colour notation, operated by matching soil against standard charts. Colour described by ‘hue’ (Spectral composition, red, yellow, blue, green); ‘value’ (dilution with white), & ‘chroma’ (darkness)
NA	Not applicable / Not applied
ND	No data / Not Determined
NS	Not sampled (in soil profile descriptions)
NSSC	National Soil Services Centre, DRDS, Semtokha
OC	Organic carbon
OM	Organic matter
P	Phosphate

PD	Poorly drained (soil)
PM	(Soil) Parent Material
Pptn	Precipitation, rainfall
pH	Measure of acidity - alkalinity
Profile	Sequence of horizons from surface down to unaltered parent material
Rectilinear	Straight slope with more or less similar gradients up- and downslope
Ri	Stream or river (Sharchop)
RNR-RC	Renewable Natural Resource – Research Centre
SCB	Soil classification of Bhutan
Series	Main group of soil classes in Bhutan. Also sixth highest level of subdivision in USDA Soil Taxonomy
Si / Z	Silt (intermediate sized mineral particles in soils, 2 - 50 um in diameter, important store for plant available water, make soils slippery & vulnerable to surface erosion and capping, aka Z, Zi)
SMR	Soil Moisture Regime, defined in Soil Taxonomy
SMU	Soil mapping unit
SoB	Survey of Bhutan
Solifluction	Summer movement of saturated thawed surface material over top of ermanently frozen subsoil. Occurs in periglacial conditions
Solum	True soil, in which soil processes have removed many traces of parent material structures
sp, spp	Species (singular & plural)
SPAL	Soils and Plant Analysis Laboratory, NSSC, DRDS, Semtokha.
Spur	Plunging ridge off side of mountain or main ridge down to valley, alternates with re-entrants
SS	Soil Surveyor
SSS	Senior Soil Surveyor
ST	Soil Taxonomy (USDA system of soil classification)
STR	Soil temperature regime, defined in Soil Taxonomy
Surface wash	Movement of individual surface soil particles by running surface water.
SWXD / SXD	Some what excessively well drained (soil)
Tr	Trace
TEB	Total exchangeable bases (= exchangeable Ca + Mg + Na + K)
Terrace, river	Bench along side of river valley where old alluvium has been left by down cutting of river bed
Terrace	Flat field created by levelling sloping land. Used for wetland rice, & enclosed by bund to retain irrigation water.
TN	Total nitrogen
USDA	United States Department of Agriculture
VPD	Very poorly drained (soil)
WD	Well drained (soil)
WRB	World Reference Base
WT	Water table
XD / XWD	Excessively well drained (soil)
Z, Zi	Silt (intermediate sized mineral particles in soils, 2 - 50 um in diameter, important store for plant available water, make soils feel slippery & vulnerable to surface erosion and capping, aka Si)

1 INTRODUCTION

1.1 General

This is the technical report of the semi-detailed soil survey of the main areas of arable lands of Punakha Dzongkhag, West Central Bhutan. This report includes a full account of the landforms and soils, and descriptions of representative soil profiles and summarised chemical analyses. This report is for those who wish to know about the soils in detail. The summary should supply the information for non-specialists requiring less detail.

Previous soil surveys undertaken by the Bhutan Soil Survey (SSU) have been requested by colleagues in the RNR sector. They have covered limited and specific areas of particular interest, such as research stations, intensive study watersheds etc. Many of them have been at detailed scales (1:1000 – 1:5000). As well as being of interest to colleagues in the RNR sector, these soils surveys have been useful for training during the early years of SSU. They have also given SSU a useful introduction to the soils of Bhutan. Nonetheless, they have been carried out *ad hoc* and piecemeal. The areas covered are small and not systematically distributed.

It is now necessary to start a systematic programme of soil surveys of substantial areas. These surveys will gradually build up to a picture of the soil resources of the country. They will also put the results of the earlier detailed surveys into their national and regional contexts. Such surveys also fit in with the planned development of SSU, as Activities # 3.1 and 4.1 in the 1996 Inter-governmental Agreement for the Bhutan Soil Survey Project.

Importance and ease of access determined the sequence in which to survey the soils of the large agricultural areas. Taking an area within easy range of Simtokha enabled frequent visits by the Soil Survey Specialist, an important consideration at the early stage in the development of SSU. The valley of Thim Chhu was rejected because of the likely loss of substantial areas of agricultural land to urban and peri-urban expansion in the future. The valley of Puna Tsang Chhu (Wangdue – Punakha) was preferred to that of Pa Chhu (Paro) on account of its greater agricultural extent and importance.

It was originally intended to survey and report all of the main areas of arable land in the mid-latitude section of the valley of Puna Tsang Chhu, from Botokha and Dawakha in the north to Baso Chhu in the south, as a single survey. However progress was slower than expected, due to training activities, and because of the complexity of the landscape. The valley has therefore been taken in two sections; the northern section in Punakha Dzongkhag, which is covered in this report, and the southern section in Wangduehodrang Dzongkhag, which will be done separately at a later date.

A small part of the area, the catchment of Nyakalumpa Chhu, has been surveyed and reported separately, as a training exercise (SSUP Report SS10, 1999). Its data and findings are incorporated into the present report and maps.

1.2 Aims of the soil survey of the arable lands of Punakha

This semi-detailed soil survey of the main areas of arable land of Punakha was undertaken with objectives of:

- Providing information on the nature and distribution of the main arable soils of the area, particularly for the dzongkhag RNR and planning staff and for Bajo RNR-RC.
    - Indicating the extent to which the soils of previously surveyed areas in West Central

Bhutan, particularly those of Bajo RNR-RC (SSUP Report SS3 (a), 1998) and the Lingmutey Chhu watershed (SSUP Report SS5 (a), 1999), are typical of the region.

- Introducing SSUP staff to the procedures and methods for soil surveys of large areas.
- Providing SSUP with further data for the development of a national soil classification, land evaluation systems, and national and regional soil maps.

2 SURVEY AREA

2.1 Location, extent and access

The survey area includes:

- The valley floor of the main N-S rivers in Punakha Dzongkhag, i.e.
- Puna Tsang Chhu, from Punakha down to mouth of Tabe Rong Chhu,
- Mo Chhu (mainly west bank) from Punakha up to Botokha
- Po Chhu (mainly east bank), from Punakha up to Dawakha.

- The arable areas in the main E-W tributary valleys, i.e. Nyakalumpha Chhu, Shiri Rong Chhu and Shengana Chhu.

- The arable hill land in the Talo-Walakha-Norbugang and Wangkha-Dawakha areas.

The boundaries of the area surveyed are shown in Figure 2.1. The boundaries are arbitrary straight lines chosen for mapping convenience as long as the main arable areas are included. The total area and the area of slope soils is therefore arbitrary. The area stretches in latitude from 27^0 31' N to 27^0 40' N, and in longitude from 89^0 45' E to 89^0 57'E. It covers about 6900 ha (about 17000 acres) and includes all of the extensive contiguous areas of arable land in the dzongkhag. However there are small, isolated patches, high up on hillsides, that are not covered.

Virtually all of the survey area is in Punakha Dzongkhag, and includes parts of Talo, Guma, Labjisa, Shengana, Lingmukha, Dzoma, Bjimena and Chhubu geogs (spellings as per DDC, 1998). However a few hamlets and households are affiliated, by long-standing traditions, to Wangduephrodrang and Thimphu Dzongkhags, even though surrounded by Punakha land and neighbours.

The west (true right) bank of Mo Chhu is served by the blacktop road from Metsina through Punakha almost to Tsirigang. The road continues further upriver as an all-weather gravel road to beyond the northern boundary of the survey area. It currently terminates for vehicles at Trashitang, but is being extended to Gasa Dzong. There is a black-topped spur from the Metsina – Punakha road, uphill through Walakha and Laptsakha to the Talo -Norbugang junction. From there it continues westwards as an all–weather graveled branch up to Talo Gompa, with another northwards to the village of Norbugang.

The east (true left) bank of Po Chhu is served by a more or less all-weather graveled road from Wangdi to Tsephu Chhu. There is a community road from there to Jibjokha at the north-eastern corner of the survey area, but this is not easily motorable in wet weather. There is a spur off the Tsephu road, for about 8 km up Shengana valley, through Shengana village, and ending at Dado Gompa.

The least accessible areas during our fieldwork were the upper and middle sections of the tributary valleys, such as Siri Rong Chhu and Nyakalumpha Chhu. However, even these are within a few hours walk from the nearest roadside.

Figure 2.1 Location map

Compile map and insert

2.2 Climate

The survey area has an altitude range from about 1150 to about 1800m a.s.l., and has a subtropical - warm temperate climate. The temperature data for Punakha and Shelgana (MTI spelling) are summarised in Tables 2.1 (a) and (b). Mean maximum temperatures at Punakha, altitude about 1180 m a.s.l., on the floor of the main valley, range from about 18 ^{0}C in January to about 30-31^{0}C in June - August. The corresponding figures for Shelgana, at 1680 a.s.l., 7 km east of Punakha in the middle section of one the main E-W side valleys, are 18 ^{0}C and 26 ^{0}C. Mean minimum temperatures at Punakha range from about 5 ^{0}C in January to about 20 ^{0}C in July – September (5 ^{0}C and 16 ^{0}C at Shelgana). The winter temperatures are similar but the summer temperatures are distinctly higher at Punakha. This may be due to the reduction in the monsoon cloud cover above the main N-S valley by the up-valley wind, and the relative weakness of this effect in the side valleys. It is assumed that the boundary between subtropical/ warm temperate temperature regimes is at about altitude 1400 m a.s.l.

Even allowing for 1-2^o C depression of soil temperatures relative to air temperatures, the soil temperature regimes (STR) at both stations are thermic, as defined by Soil Taxonomy (Soil Survey Staff 1999). This more or less accords with estimates that the boundary between mesic and thermic STR is between 1600 and 1900 m asl in Lingmutey Chhu (SSUP Report SS 5a, 1999), and between 2000 and 2200 m asl in Radhi in Eastern Bhutan (SSUP Report SS 6a, 2000).

The survey area lies in the northern part of one of Bhutan’s dry valleys. These are areas of low rainfall and xeric vegetation that occur in the middle sections of many deeply incised N-S valleys in the Eastern Himalayas. The dry areas are confined to the floors and lower slopes, and the surrounding hills have mesic forest vegetation. Ohsawa (1987) identified six main dry valleys in Bhutan. The most pronounced are those of Ku Ri and Gong Ri in the east of the country. The middle part of the valley Puna Tsang Chhu is the most pronounced in central and western Bhutan. Ohsawa estimated its Aridity Index as more characteristic of grasslands, and concluded that that the climate should not be able to support forest on the valley floor.

Eguchi (1997) suggested that there are two sets of factors, operating at different spatial scales, which give rise to dry valleys in Bhutan. With reference to the survey area, these are:

On the larger, synoptic scale, the Black Mountains and Dagala massif to the south are split only by the narrow gorge of the lower Puna Tsang Chhu, and form an almost continuous barrier to the monsoon. There is high orographic rainfall on foothills in the south of the country, and the floor of the middle valley is in relative rainshadow.

At a local scale the narrow gorge in the south appears to funnel and strengthen the valley wind that blows northwards, i.e. upstream. This wind blows fiercely for most afternoons except in the monsoon (‘Windy Wangdi’) and prevents the formation of cloud over the valley bottom (Eguchi 1991). Cumulus clouds form along the main N-S ridges and make the middle and upper hill slopes significantly wetter than the valley floor. Eguchi suggested that the dry valley effect is less felt in the E-W side valleys, because of their cross-wind alignment. The strength and duration of the valley winds adds to the moisture deficits for vegetation in the valley bottom by increasing the rates of evapotranspiration.

The rainfall data summarised in Tables 2.1 (a) show that the mean annual total at Punakha is about 750 mm, of which about 600 mm (74%) fall during the monsoon months of May – September. The rainfall at Shelgana averages 1360 mm per year, of which about 900 mm (66%) falls in the monsoon. Comparison of Punakha and Shelgana supports Eguchi’s (1997) suggestion that the floor of the main valley is considerably drier than the side valleys.

There are no hillside met stations in the survey area, so we have no quantitative indications of how rapidly rainfall increases upslope. There are data for a couple of years from Dochula, where the annual rainfall appears to be about 1800 mm. However Dochula is over 14 km from and almost 1800 m higher than the survey area. It is thought to give little indication of what happens on the lower slopes in the survey area.

Table 2.1(a) Climatic summary for Punakha 1985-1998

Months	J	F	M	A	M	J	J	A	S	O	N	D	Year mean or total
Temperature (^{0}C)													
n (number of complete records)	*9**	*9**	*12**	*11**	*11**	*11**	*11**	*11**	*13**	*13**	*13**	*13**	***10***
Mean	12	14	17	19	22	20	25	26	25	22	17	14	**20**
Mean minimum	5	7	10	13	16	19	20	20	20	17	11	8	**14**
Absolute minimum	1	2	4	8	9	14	17	13	15	7	3	1	**1**
Mean maximum	18	20	24	25	27	30	30	31	29	27	23	20	**25**
Absolute maximum	25	26	30	34	35	**36**	35	35	35	32	30	29	**36**
Rainfall (mm)													
n (number of complete records)	*12**	*12**	*12**	*11**	*11**	*11**	*11**	*11**	*13**	*13**	*13**	*13**	***11***
Mean	14	8	22	41	63	117	179	159	95	48	5	5	**762**
Monthly maximum	40	27	67	103	101	172	263	239	152	144	19	20	**907**
Monthly minimum	0	0	0	20	68	77	97	0	64	6.4	0	0	**549**
Highest daily rainfall	16	18	44	30	44	57	**80**	40	35	65	19	17	**80**

* Includes records with monthly summaries but incomplete daily data   Source: Data from MTI

Table 2.1 (b) Climatic summary for Shengana 1985-1997

Months	J	F	M	A	M	J	J	A	S	O	N	D	Year mean or total
Temperature ^{0}C													
n (number of complete records)	*13*	*13*	*13*	*13*	*12*	*12*	*12*	*12*	*12*	*12*	*12*	*12*	***12***
Mean	11.6	12.7	14.9	17.0	18.8	20.3	21.3	20.9	20.6	18.3	15.7	13.4	**17.1**
Mean minimum	5.5	6.5	8.3	9.9	12.1	14.5	16.2	15.4	15.1	12.3	9.0	6.6	**11.0**
Absolute minimum	**0**	1	1	3	3	4	4	6	6	4	3	**0**	**0**
Mean maximum	17.7	18.9	21.5	24.2	25.4	26.2	26.4	26.4	26.1	24.4	22.5	20.2	**23.3**
Absolute maximum	28	27	29	31	33	**34**	**34**	33	**31**	30	32	33	**34**
Rainfall (mm)													
n (number of complete records)	*13*	*13*	*13*	*13*	*12*	*11*	*12*	*12*	*12*	*12*	*12*	*12*	**11**
Mean	16	36	42	88	129	203	305	247	167	58	29	18	**1360**
Monthly maximum	36	68	119	134	218	284	400	352	416	202	62	46	**1633**
Monthly minimum	5	5	18	56	47	145	211	133	105	12	0	0	**1109**
Highest daily rainfall	19	28	29	33	34	74	60	60	**88**	62	16	20	**88**

Source: Data from MTI

Table 2.2 Climatic summary for Gasa 1985-94, 1996-1998.

Months	J	F	M	A	M	J	J	A	S	O	N	D	Year mean or total
Temperature (^{0}C)													
n (number of complete records)	11	11	12	12	12	12	12	12	12	11	12	11	***11****
Mean	4.1	5.8	7.7	9.8	14.5	15.1	15.0	15.9	15.5	13.1	9.6	5.3	**11.0**
Mean minimum	0.3	0.3	1.1	2.7	5.0	6.3	9.0	7.7	7.4	3.3	0.3	0.8	**4.0**
Absolute minimum	**-11.0**	-9.0	-7.0	-2.0	2.0	1.0	5.5	2.0	2.0	-4.0	-9.0	**-11.0**	**-11.0**
Mean maximum	14.3	16.0	17.5	19.0	23.0	26.7	26.5	25.5	24.1	22.9	19.5	16.2	**21.0**
Absolute maximum	22.0	20.8	20.0	22.0	26.0	28.0	**29.0**	27.0	26.0	**29.0**	26.0	21.0	**29**
Rainfall (mm)													
n (number of complete records)	11	11	12	12	12	12	12	12	11	12	11	11	**11***
Mean	10	35	65	87	202	275	489	398	299	143	40	30	**2073**
Monthly maximum	34	95	188	170	292	414	970	615	419	225	84	71	**2761**
Monthly minimum	0	15	6	0	83	74	358	270	196	35	0	0	**1481**
Highest daily rainfall	19	24	23	34	45	45	**105**	89	50	82	66	21	**105**

* Includes records with monthly summaries but incomplete daily data

Source: Data from MTI

The aridity of the valley of Mo Chhu diminishes upstream, and is less pronounced near the northern edge of the survey area. The vegetation grades into lush broadleaf forest northwards from about Botokha (Ohsawa 1991) and the diversity of the bird fauna also increases (A. Pain pers.comm., 1999). The Gasa met data, as summarised in Table 2.2, also indicate that the rainfall increases upstream in this part of the Mo valley. However, Gasa is about 1000 m higher than and 22 km north of Botokha, so that its data are no more than roughly applicable to the survey area. Judging from the vegetation and the persistence of chir pine on the hills, the northwards increase in rainfall may be slightly weaker up the valley of Po Chhu. This may be due to its N-S alignment, allowing for a stronger northwards extension of the dry valley wind effect, but we have no data to confirm there is a real Mo/Pho difference. The general pattern is therefore assumed to of increased rainfall from about 750 at Punakha to about 900 going up the main Mo and Po Chhu valleys to the northern boundary of the survey area, and up to as much as 1500 in the main side valleys.

The moisture regime of the soils on the floor of the main valley is thought to be ustic. The ustic designation was too widely applied in earlier SSU surveys and many of the soils in Bhutan are now thought to have udic SMR. However non-irrigated soils of the main dry valleys, including those in this survey area, are probably dry for more than 90 consecutive days, and are truly ustic. The lower slopes and the side valleys have climates that are sufficiently cool and moist for their soils to have udic SMR's.

Overall the climate of the survey area appears to grade from dry subtropical in the southern part of the main valley floor to subhumid and warm temperate going upslope, upstream and into the side valleys. Rainfed vegetation in the main valley appears to experience considerable moisture deficits, which are intensified by the persistent strong winds (Ohsawa 1987).

Table 2.2 landscape

2.3 Solid geology

Because the survey area is larger and more complex than any surveyed previously by SSU, the description of the soil materials is broken into two stages, i.e. bedrock in this section, and surface materials in section see 2.4.

There have been a considerable number of geological investigations in the area (see References for details). As well as general geological mapping, there have also been surveys for economic minerals, particulalry for scheelite, an important ore of tungsten.

Most of the area is underlain by the high grade metamorphic rocks of the Thimphu Group. These were formed by intense and prolonged pressure and heat as they were compressed during the northwards subduction of the Indian under the Eurasian plate. The rocks were squeezed southwards as a series of thrust sheets. The main rock types are gneisses and quartzites. The gneisses vary in structure from granitic through augen to well foliated, almost schistose. Silvery looking muscovite is the main mica, but there are some darker biotite gneisses. The quartzites occur as veins and beds of varying thickness, some of them quite massive. There are also some calcareous bands, a few of them several metres thick and with outcrops that can be traced for several kilometres. They are nearly all sufficiently metamorphosed to qualify as marbles. There are also mafic and ultramafic intrusions. As well as the granitic gneisses, there are intrusions of anatectic granite, varying in size with some up to hundreds of metres across. Some of them are coarse grained and pegmatitic.

A distinctive feature of the soils on the Thimphu Formation outcrop in the survey area is the occurrence of extensive areas of deep, bright red clays. Several of the geological accounts link this kind of weathering with skarn rocks (e.g. Lakshminarayana, 1994). These calc-silicate rocks are formed by the contact metamorphism of limestones, marbles and possibly also mafic rocks in the aureoles surrounding large granite intrusions. However, in the field, the red clays also appear to be associated with biotite gneisses. The provenance, formation, properties, and management implications of these extensive soils is one of the topics that will be investigated by the forthcoming joint pedological research programme by NSSC and the Technical University of Munich.
The rocks underlying the upper part of the Shengana valley are Tethyan. They were laid down as marine sediments in the former Tethys Ocean, which used to lie between the Indian and Eurasian continental plates. As the Indian plate moved northwards against Eurasia, the ocean was compressed and eventually disappeared. Its floor was forced upwards and much of the Tibetan plateau is formed from the derived marine sedimentary rocks. They were subject to pressure, heat and deformation during their compression and uplift. The Shengana rocks are part of the Black Mountain block, which is a separate outcrop of the Tethyan, and not a southwards extension of the Tibetan Tethyan basin. The Black Mountain Tethyan rocks may have been rafted into their present position when the underlying sheets of gneiss of the Thimphu were thrust southwards during the Himalayan orogeny. The rocks of the Black Mountain are Lower and Middle Tethyan in age, and contain Paleozoic fossils (Singh 1978 a, b & c; Chaturvedi et al. 1983; Ganesan 1982; Ganesan & Bose 1982).

The Tethyan rocks in Shengana belong to the Chekha Formation, the main rock types of which are phyllites, quartzites and limestones. In Shengana there appears to a high proportion of intrusions, and granite is one on the most extensive rock types. No outcrops of mafic or ultramafic intrusions were seen, but mafic clasts are common in the surface drift materials (see 2.4). The main differences between the Thimphu and Chekha formations are summarised in Table 2.3.

Table 2.3 Main solid rock formations in Punakha survey area

Formation	Age	Grade of metamorphism	Dominant rock types	Other rocks, including intrusives
Chekha	Paleozoic	Low-moderate	Phyllite, Quartzite, Locally Granite	Schist, Limestone, Amphibolite
Thimphu	Pre-Paleozoic	High	Gneiss, Quartzite	Marble, Granite & pegmatite, Skarn, Amphibolite

2.4 Surface drift ad soil parent materials

Few of the soils in the survey area are derived directly from underlying bedrock, and most are formed in surface materials that have been detached abd transported.

There are six main types of drift in the area, i.e.

2.4.1 Main river alluvia

These occur in valley floors along main N-S rivers, i.e. Mo, Po and Puna Tsang Chhu. The deposits are well sorted, with distinct layering of contrasting textures & particle size. The gravel and stones contain exotics, which are derived from formations in the High Himalaya upstream of the survey area. The boulders, stones, gravels and sands in the main river alluvia are concentrated in layers and are well rounded. There are several sets of alluvium left as natural terraces along the sides of the valley. These increase in age with height above present river level.

Each terrace represents a separate cycle of deposition. During the early parts of each cycle large volumes of coarse alluvium are deposited, so that the base of each unit consists mostly of boulders, stones, gravel and coarse sand, many metres thick. As the river stabilised each new level, the speed of flow, and therefore the volume and particle sizes of the alluvium all decreased. The top few metres of each unit are almost stone-free, and consists mainly of fine sand, silt and clay. If the river is placid enough in the later stages of the cycle, back-swamps may develop and the upper fine grained deposits may include organic layers. In the survey area peat was seen only in the highest terrace (80 m) at Jibjokha

Stones in the older terraces have weathered since deposition. Some of them are now too soft to survive the kind of battering and abrasion (= scraping) they received when they were transported and deposited by fast-flowing mountain torrents.

The alluvium of the current cycle has not yet progressed through to a long period of silt accumulation. The deposits of the current floodplain and lowest terrace are sandy, with boulders at shallow depths. The absence of silt and clay, and the purity of the sand makes these deposits suitable as construction materials.

2.4.2 Fan alluvia

These are sloping deposits filling floors of valleys of larger side streams ('rong chhu'), such as Nyakalumpa, Shoshi, Shengana and Tsephu Chhu. The deposits are of mixed particle sizes, and include angular-subrounded stones and boulders. There is some layering but much of the material is unsorted and randomly oriented. The fans are not thought to be current and are presently being dissected by modern streams. Ikemoto's (pers. comm. 2000) study of Thimphu valley suggests that some fans are mudflows, deposited in one very large slump at a time when there is a lot of loose material and large volumes of water, especially when large glaciers are melting. The deposition may have been occurred when temporary dams due to large landslips are burst.

The larger side streams are cutting down into fans and have deposited small patches of fan terrace. These deposits are intermediate between main river (layered with rounded stones) and fan alluvia (non-layered with angular stones).

There is a high level (ca 100 m above the current level of the Po Chhu) deposit on the TRB (west) in the Nawakha – Jangwakha area. This is deep, highly weathered, un-layered and contains no rounded stones. The surface has a steeper slope (about 5-10%) than main river terraces, so the deposit is interpreted as a high level remnant of coalesced foothill fans, or lower slope colluvium, deposited at a time when the river level was considerably higher than at present. This deposit is older than, and distinct from, the side valley floor fans .

2.4.3 Colluvium

This is material that is moved slowly down hillslopes by the combination of gravitational creep, small-scale slumps, and surface wash. It has travelled only a short distance down a single slope. Colluvium usually consists of un-layered mixtures of soil and stones. The frequency of the stones ranges from zero to abundant. They are randomly oriented and mostly angular and subangular. The fine earth matrix does not usually show textural layering. Colluvium tends to accumulate on lower slopes, particularly if they are concave. As most of the hill lands in the survey area consists of lower slopes, they are nearly all mantled with colluvial deposits. Many colluvia were deposited in several phases, some of which were sufficiently separated for stable topsoils to have developed, to be subsequently buried by fresh colluviation.

2.4.4 Old landslide deposits

These are not easily distinguished from colluvium. They are also un-layered mixtures of soil and randomly oriented angular and subangular clasts deposited on hill slopes. Recent landslips can usually be distinguished by their jumbled and bare surfaces. Subrecent landslips can usually still be identified by the combination of a headwall, sidewalls, concave runout area, and generally rumpled surface. These features tend to be smoothed out or removed with time. They also get removed by the construction of terraces for irrigated agriculture. Few unequivocal landslips were seen in the survey area. This confirms observations elsewhere in Bhutan that slopes on the Thimphu gneisses and their colluvia are mostly stable in the climatic conditions of mid-latitude Bhutan.

2.4.5 Aeolian.

A feature of many soils in the area (and in many parts of Bhutan) is the high content of silt and very fine sand in the upper layers. In residual and colluvial soils some of this may be generated by weathering of the local bedrock. In alluvial soils some may be due to textural segregation during transport and deposition. However many of these layers are thought to be due to aeolian (windblown) deposition during previously drier palaeoclimates. Gradual accumulation of aeolian silt and very fine sand may account for the increase in thickness of the stone-free silty layers with increasing height and age of the river terraces.

It has been suggested that the main sources for the dust were the moraines and glacial lake beds of Tibet, which were probably more extensive than now during the colder spells in the Quaternary. Extensive ice sheets at that time could have blocked and weakened the effects of the southwest monsoon, so that the wind pattern was not so dominated by the valley winds from the south as it is now. An alternative source could have been the Indian plains at a time when the surface soils were dry and the natural vegetation was more sparse than at present. In this case the sediments could have been transported by wind patterns similar to those of the present.

Fresh aeolian deposits have high silt and very fine sand contents, are stone-free, and very porous. The aeolian deposits in the survey area appear to be quite old, and most have been reworked by surface wash, animal action, and by cultivation since deposition. The high porosity has been reduced, but other aeolian characteristics remain.

2.4.6 Gully Wash

Gully wash and stream bed deposits form a minor group of materials. These are current and very recent deposits of jumbled boulders and sand in beds of steep minor streams. They occupy narrow areas and can be ignored in semi-detailed soil surveys.

Another type of deposits that should be mentioned is lacustrine. It has been suggested that Puna Tsang Chhu was at one stage dammed by a massive landslip from the slope on the west bank, near Rinchengang, into the river at the site of Wangdi bridge. The river backed up and formed a temporary lake, which may have stretched upstream as far as Punakha (M Motegi pers. comm. 2000) If this did happen, some of the intermediate or higher terraces along the sides of the main valley may have been deposited in the still waters of a lake, rather than by a fast flowing river. This may account for the finer textured alluvia on the higher terraces, compared with the sand and boulders of recent alluvium. The Jibjokha high terrace, with its buried peat layer could be lacustrine but no really convincing lake deposits have been seen in the survey area, unlike at Bajo and Limbukha further downstream in the Puna Tsang Chhu drainage system.

Many soils are formed in layered mixtures of different materials. The commonest combinations are;
Aeolian surface deposits over, and mixed with, alluvium and colluvium.
Colluvium over fan alluvium at base of footslopes in side valleys
Side valley fan deposits over river alluvium of middle and low main river terraces at the front edges of some fans
Thin layers of main river alluvium over locally derived fan alluvium and alluvium,

2.5 Topography

Because the survey concentrates on the main blocks of arable land, the survey area is mostly located on the landforms of the valley floors and lower slopes, with a few areas on middle slopes. It does not extend uphill to include upper slopes, summits or crests.

2.5.1 Floors of main N-S valleys

The longitudinal (down-valley) gradient of Puna Tsang Chhu from the confluence at Punakha to the mouth of Tabe Rong Chhu, the southern end of the survey area, is gentle by Bhutanese standards, with a fall of only 20 m over about 6 km (ca 0.3 %). The gradients upstream are steeper. Mo Chhu falls about 120 m in 10.5 km from Akuna to Punakha (ca 1.1%) and Po Chhu falls about 100 m in 7.5 km from Jibjokha to Punakha (ca 1.3%). The floors (thalwegs) vary in width, from 300m to 1km, with the confluence area around Punakha over 1.5km wide between hill slopes.

There are river terraces along the sides of the main valleys. They are almost continuous along the TLB (east) bank of Po Chhu. They are patchy and narrow on the opposite bank of Po Chhu, and along both banks of Mo Chhu and Puna Tsang Chhu downstream of the confluence. The intervening sections are rock bluffs or where colluvial slopes come right down to the river.

The terraces do not form distinct ‘lower’, middle’ and ‘upper’ groups, so we refer to them by their approximate heights above river level. i.e.

In places the rivers are quite wide and shallow. Parts of the beds are exposed during winter, and are excavated for construction sand and aggregate.

There is an extensive terrace at about 3-5 above the present riverbed. This is not a normal flood plain, and remains above water in all but exceptional (GLOF) floods. However these areas may be submerged in the exceptionally high and violent floods that follow glacial lake outbursts (GLO). These are more likely on Po Chhu as this has many moraine-dammed lakes in its upper catchment (**, 199*). The most recent large GLO flood was in early 1994, and greatly affected the valley of Puna Tsang Chhu downstream of Punakha, as well as that of Po Chhu. It also caused considerable damage to Punakha Dzong.

There are extensive stretches of terrace at 10-15 m above river level, especially on the TLB of Po Chhu from Tsephu down to the below the confluence at Punakha. These are up to 200 m wide in places, e.g. at the lower end of the Shengana valley around Mendegang and Gubji.

There is another extensive terrace at about 30-40 m above the river that stretches from Gubji up to Tsephu. This abuts against the hillslope, and at it upper edge that alluvium is thin and overlays local colluvial or fan deposits within 2 m depth.

There are three groups o terraces at similar but slightly lower heights along Mo Chhu and along Puna Tsang Chhu downstream of Punakha. However they are less continuous and less extensive than the TLB terraces along Po Chhu.

There is a patch of higher river alluvium at about 70 – 80 m above the current river level, at Jibjoha, but there none elsewhere in the survey area, and terraces at this height do not reappear until Bajo and Wangdi.

2.5.2 Jangwakha relict fan

Although there is only one patch of clear high level alluvium, there are substantial remnants of an old, gently graded, depositional surface about 100 m above the current level of the river in the Jangwakha-Nawakha area on the TRB (west) of Po Chhu. The surface has been deeply dissected by the side streams, and now forms 5 distinct gently sloping table-like blocks.. The deposit is relatively shallow and the side stream dissection exposes deeply weathered in situ gneiss. This landform is interpreted as al local footslope deposit of colluvium or coalesced locally derived alluvial fans.

2.5.3 Side valleys

The floors of the main East-West side valleys are considerably steeper than the floor of the main valley. Nyakalumpa Chhu falls about 420 m from near Kyilekha in 4.5 km to its confluence with Mo Chhu (ca 9 %). The longitudinal gradient of the lower 6 km of Shoshi Rong Chhu is about 7*%. The lower 9 km of Shenga Rong Chhu also slopes at about 7%, and the lower 2.5 km the smaller Tsephu Chhu at about 11%.

The floors of the side valleys are filled with alluvial fans. These are much younger than the high level fan remnants around Jangwakha. Some of them, e.g. Nyakalumpa, appear to be simple single units, possibly deposited in one short burst. In other valleys there are fans of apparently different ages, separated by steep bluffs or steep rocky fan-less stretches of the valleys. This is clearly seen in Shengana, where there is a lower fan from Lungkha down to Mendegang. This has been deeply dissected with the current stream about 20 m below the fan surface. This is separated by a narrow and rugged valley section from the mid-valley fan that stretches from Gangkha down to Garakha. The mid-valley fan is a complex unit, with at least two distinct surfaces. It appears that one fan was deposited, dissected by the stream, and then a second fan was deposited in the trench. Smaller areas of separate high and low fans can be also distinguished in other places, such as in the minor side valley at Lakhu on Mo Chhu.

The fans have moderate overall longitudinal gradients, in the range 10-20%. However their surfaces are irregular in places. None of the main fans have marked transverse doming and lateral double streams, as seen in some fans in the side valleys of The Thim Chhu watershed in Western Bhutan (Ikemoto pers. comm., 2000; SSUP Yusipang Report, SS1, 1998). Some of the fans, e.g. Nyakalumpa have distinct bluffs at their lower ends, in which the fan deposits can be seen overlying main river alluvium.

The main streams of the side valleys cut down into the fans, to depths of 20 m in places. There are patches of terraces on the sides of some the larger trenches cut by the river, e.g. Nyakalumpa Chhu the lower Shengana fan, and around Botokha.

2.5.4 Hill slopes

Because of the cartographically arbitrary straight line boundaries, there are areas of rectilinear or concave lower slopes included as a surround to the main arable areas in the survey area. The survey area also includes substantial areas of hill land in the Walakha – Talo – Norbugang in sections the southwest, and Jibjokha – Dawakha - Jangwakha in the northeast

(a) Walakha – Talo – Norbugang:

This area consists of two major broad spurs running down from the Talo area. One runs slightly east of south down through Laptsahka to Walakha. It has a more or less rectilinear profile except at the bottom, where the village and lakhang of Walakha are on a broad knoll, separated from the spur upslope by a gentle col. The second main spur runs northeastwards down through Norbugang towards Punakha. It has a complex profile with a less steep section around Norbugang but steepens to give a convex profile below. There are no large 'knolls and cols' on the spur.

The area between the spurs is a complex of lesser spurs and minor (1^{st} and 2^{nd} orders) valleys. The slope gradients are moderate – steep, in the range 25 – 60%, and include concave, convex and rectilinear sections. There are areas that look like old landslip sites, but mass movement does not appear to be currently active in the area.

This is in contrast to surface and gully erosion, which appear to be very active and severe hazards. A distinctive feature of this area is the occurrence of many deep (up to 10 m) steep-walled gullies, particularly in the bright red soils on the two main spurs. Most are still quite narrow and have not so far resulted in extensive loss of land. This kind of erosion is not widespread in Bhutan, and appears to be confined to red clays and loams derived from skarn and/or biotite gneiss. Although not yet very extensive in the survey area, this kind of erosion can extend and form unusable badlands, with considerable loss of land and high sediment loads in streams and irrigation water. This kind of severe degradation can be seen around Umtekha in the Lingmutey Chhu area, about 8 km to the southeast (SSUP SS Report 5,1999).

Small areas of deep gullies and badlands occur just outside the survey area on the lower slopes on both the southern and northern sides of the Lower Shengana valley.

(b) Jibjokha – Dwakha - Jangwakha

This area is topographically quite unusual and the high level alluvium around Jibjokha and the high level fan remnants around Jangwakha are described above. The cultivation in this part of the survey area also extends up the lower slopes of the hills, especially on the TLB (eastern) of the valley of Po Chhu. The spurs have distinct knoll and col profiles. The intervening re-entrants are quite broad and gently sloping, and appear to be covered with slump/landslip/alluvial fan deposits. There are a few fresh as well as old landslips on these slopes, but they appear to be generally stable. Gully erosion is not important.

2.6 Land use and vegetation

The boundaries of the survey area have been delineated so that uch of it is arable land. There is little kamshing (rainfed field crops) and almost all of the arable cropping is on irrigated terraced land (chhushing). The main irrigated crop is single cropped summer rice. There are a few farmers, e.g. in the Dawakha area, who are double cropping rice. They raise the seedlings of the spring-sown short season variety under transparent plastic cloches.

Previously the land was kept fallow during winter, and used for grazing by cattle. However following research at Bajo RNR-RC and extension work by MoA staff, much of the land is now cropped in winter. The main winter crops are wheat and mustard, but some potatoes and other vegetables are also grown. These crops are planted in January – March and receive some starter and supplementary irrigation, although not much water is available at that time.

There are many citrus orchards in the area. These are mostly ery small and form part of the house gardens (tshesa). The produce is partly consumed domestically and locally, but some surplus is sold in local markets. The main fruits grown are mandarins.

The natural vegetation of the hillsides in Talo gewog and on the lower slopes f the Po Chhu valley is open forest dominated by Chir pine (Pinus roxburghii). This is a submesic - xeric community and has a sparse shrub and grass ground cover. In the northern parts of the valley of Mo Chhu, the forest vegetation on the lower north-facing slopes is transitional between chir pine and warm temperate broadleaf forests, with Castanopsis spp and Quercus griffithii. The broadleaf forest becomes lush and dominant further up Mo Chhu, beyond the northern boundary of the survey area.

On roadsides, field boundaries and river banks throughout the survey area there are patches of fairly dense scrub with shrubs and low trees, including Opuntia, Jatropha, Jasminum, and Rhus spp.

3. PREVIOUS SOIL INFORMATION

There are three earlier SSU surveys, which are relevant to this survey area:

3.1 Nyakalumpa valley

The Nyakulumpa Valley is actually part of the survey area. It is a semi-detailed soil survey (SSU Report 9a, 1999) that was done separately, mainly as a training exercise in field techniques for a newly assigned graduate. The survey covers about 300 ha in a major side valley of Mo Chhu, about 0.5 km north of Punakha Dzong. The area is mostly underlain by colluvium on the hillslopes and fan alluvium deposited by Nyakulumpa Chhu. There are also small areas of lower and middle main river alluvial terraces deposited by Mo Chhu.

The most extensive soils on the hill slopes are derived from the gneiss and quartzite. They are greyish brown to dark brown, with mainly loamy sand to sandy loam textures. Their depths range from 90 cm to 150 cm over weathered rock. There are also deeper and intensively gullied red hill soils derived from skarn rocks, consisting of strong brown over dark reddish brown sandy clay loam.

The soils of the alluvial fan have greyish brown sandy loam topsoils. Those on gneissic alluvium have grey and brown subsoils, whilst those on alluvium derived from skarn are reddish. Both types have textures ranging from sandy loam to sandy clay. The soils of the middle terrace along the Mo Chhu consist of olive grey to greyish brown silty upper part overlying a yellowish brown to brown, weathered, more sandy and more friable lower section with layered textures of sand, sandy loam and sandy clay loam. The soils of the lower terrace also have grey and greyish brown, silty upper horizons. This tends to be finer textured than in middle terrace soils. The lower section of the lower terrace soils is loose, pale fine sand with lenses of silt, similar to the white sand currently being deposited by the river.

3.2 Lingmutey Chhu

The semi-detailed soil survey of Lingmutey Chhu (SSU report 5a, 1999) covers the next main side valley to the south of Shengana. The survey covers the whole of the watershed, including pasture and forest lands. It covers about 33 km^2, and stretches from about 1200 m altitude, along the main Puna Tsang Chhu river, to above 3000 m. The geology is varied and the underlying rock types include gneiss, schist, limestone, amphibolite, skarn and quartzite. These mostly belong to the Thimphu group. There appear to be Tethyan rocks of the Chekha formation, including substantial intrusions of granite, in the eastern end of the valley. The surface deposits include main river alluvial terraces along Tsang Chhu, an old lake or marsh above Limbukha village, and hillwash and landslip deposits on many hill slopes. Lingmutey Chhu has no significant alluvial fan, in which it differs, from the main side valleys in the current survey area

The Lingmutey Chhu soils most relevant to those in the survey area are those of the alluvial terraces along Puna Tsang Chhu. The lower terrace soils have silty, hard topsoils over loose white sand and beds of rounded river boulders at shallow depths. The upper horizons in the profiles of soils on the middle and upper terrace are similar to those of the low terrace. However the silty layers are deeper, and there are no boulder beds or sand layers in the top two metres.

There are extensive grey and brown sandy loams in hill slope colluvium derived from gneiss. These vary in depth according to the slope and local variations in the erosion and deposition of hillwash. There are also extensive erodible red clays formed from skarn or amphibolite parent materials.

3.3 Bajo RNR-RC

SSU did a detailed soil survey of the Bajo Renewable Natural Resources Research Centre (SSU Report, SS 3 (a) 1998). The Centre occupies 26 ha on the east bank in the main valley of Tsang Chhu, about 4 km south of the present survey area. It is mostly located on main alluvial terraces at about 10m and ca 25m above current river level, with small areas of hillslope and the lower part of the connecting slope up to the 50m terrace. Most of the soils are derived from mixed alluvial parent materials from the upper catchments of Mo and Pho Chhu.

The most extensive soils are on flats of the middle and lower river terraces. The soils of the middle terrace consist of a hard, greyish brown silty upper part overlying a reddish, weathered, more sandy and more friable lower section. The depth of the upper part is variable, and tends to decrease upslope. The soils of the lower terrace also have a hard, grey and greyish brown, silty upper part. This tends to be finer textured and even harder than the equivalent layer in the middle terrace soils. The lower section of the low terrace soils is loose, pale fine sand, similar to the white sand currently being deposited by the river. The depth of the hard silty upper layer varies and, in contrast the middle terrace soils, tends to get deeper on the higher sites, away from the river. There are small areas of bouldery soils on the steep riser slopes connecting the terraces. The floodplain has predominantly pale, loose, fine sandy soils.

This survey is useful because it gives a detailed picture of the variation within the main river alluvial soils

3.4 Other studies

Three other studies are relevant to the present survey, although none are full soil surveys with soil classes and soil maps.

Drukpa (1996) is a general land evaluation of the Umtekha - Misina area, on either side of Puna Tsang Chhu about 2-4 km to the south of the present survey area. 22 soil profiles were described and analysed. These are located on terraces of the main river, the large fan/landslip unit in the Misina area, and colluvial lower slopes.

The Wangdi Groundwater study by Pacific Consultants International for MoA and JICA (PCI 1996) covers the valley floor and lower slopes of the main valley of Puna Tsang Chhu from the southern boundary of the present area to south of Wangdi town. They did not map soils but their output includes useful contour, landform, and geological maps. The geological maps are actually of surface materials, with bedrock indicated only for the shallower soils on hills. The other hillslopes are mapped as drift materials, such as landslides, colluvium or landslide blocks. The text does not define or describe these materials.

The study of Kashi geog by LUPP (1997) covers an area to the east of the present survey area. Tethyan rocks of the Chekha and Wachi La groups underlie much of Kashi (Bhargava 1997). The soil parent materials derived from these are similar to the eastern parts of the valley of Shengana Chhu. There are some outcrops of the Thimphu formation in Kashi which give parent materials that are similar to the rest of the present survey area. The Kashi study includes 21 described and analysed soil profiles. Those similar to soils in our survey area are correlated in Chapter 6.

4. METHODS

4.1 Field

The fieldwork for this survey was done intermittently between January 1999 and May 2000.

The soils were examined on a routine basis at 1081 sites, mainly with a 1.2 m Edelman auger, fitted with a 7 cm combination head where possible, but switching to a 7cm stony soil head where necessary. Duplicate augerings were done at 17 sites, where the first attempt was stopped by stones at less than 50 cm. The proportion of repeat augerings needed (<2%) was lower than in previous SSU soil surveys, because this survey concentrates on valley floors and lower slopes, where most of the soils are formed in thick drift and tend to be deep.

Most of the routine observations were sited at 50 m intervals with a measuring tape along straight line compass traverses, shown on the base maps, aligned up and down slope. The locations of traverse start and end points, and also some intermediate waypoints, were checked with a global [positioning system (GPS). Some sites were located at 10 or 20 m altitude intervals, measured with an altimeter, along tracks or paths that can be located on the base maps.

For routine soil observations the following site data were collected:

> Location, GPS; general topography and site position; the angle (in %), aspect, length and form of the slope; solid geology and drift parent material; general land use and current crops/vegetation; irrigation type; artificial land shaping features; fertiliser use, if present and if known; site drainage and surface stones.

The soils were described according to their natural layering (horizons), in the upper 1 metre. The following data were collected for each horizon:

> Munsell colour of matrix (in field moisture condition); number, size, contrast and colour of mottles; field texture; number, size and type of stones; moisture condition; and consistence on the auger.

The soils were described in more detail at 192 sites. 184 of these were done in purpose-dug profile pits, and the remaining 8 in cuttings, cleaned back to show fresh soil.

The site data were the same as for the routine sites, with the addition of a detailed description of surface features, including:

> Microrelief, rock outcrops; stones, litter, cracks, faunal activity, and capping.

The soils were described by horizons according to international conventions (FAO 1990). The data collected for each horizon were the same as in the routine descriptions, with the addition of:

> Strength, size and type of soil structure; number and size of pores, presence, strength and continuity of cutans (shiny coatings on surfaces of soil structural units); consistence in situ and in hand; number size and type of roots; reaction to HCl (to test for presence of free carbonate minerals); concretions of iron, manganese or other secondary formations; presence and effects of animals (wormcasts etc.); any other features (e.g. charcoal); clarity and shape of lower boundaries.

The main horizons of all of the profiles described in detail were sampled for analysis.

The 1390 sites in * ha , gives an overall observation density of * / ha, which qualifies this as a semi-detailed survey by international standards (SSU TD1, 2000).

4.2 Mapping

Much of the area is covered by the recent revision by Survey of Bhutan (SoB) of the old topographic mapping by the Survey of India (SoI), and this is used as the base map as far as possible.

The SoI mapping was published at a scale 1:50 000, with contours at intervals of 40 m. The survey area falls on sheets number 78E/14. This was published in 1964 and is based on smallscale aerial photography from 1956-1960, and ground control from 1960-1.

The revised mapping by SoB was published in 1998 at scale of 1:25 000, based on aerial photographs at a scale of 1:30 000 from 1987-8, and with subsequent ground verification. Sheets 78E/14SW and 78E/14SE cover the southern two thirds of the survey area. However the revised mapping stops at 27^{o} 37'30'' N (the latitude approximately of Lakhu-Hebesa on Mo Chhu and Tsephu on Po Chhu).

The 1:25 000 SoB maps were used as the soil survey field sheets where possible, i.e. the southern section. Double-magnified photocopies of the relevant sections of the SoI 1:50 000 sheet were used for the northern sections, up from Lakhu to Akuna on Mo Chhu and from Tsephu to Dawakha on Po Chhu.

The 1987-8 aerial photography is at a smaller scale than the field sheets and the print quality is variable. It is of limited use for semi-detailed soil mapping. The GIS unit in LUSS supplied an ERDAS classification of a 1998 Landsat TM scene of the area. This gave a useful overview of the topographic structure of the area and of the land cover. However, with a pixel size of 30 m, its resolution is insufficient to be useful for the delineation of detailed topographic and soil boundaries.

4.3 Laboratory

587 soil samples were collected from the main horizons of the 192 detailed profiles were analysed by the Soil and Plant Analytical Laboratory (SPAL) of NSSC of MoA at Semtokha.

The first *** samples were analysed for organic matter characteristics, base status, and particle size classes. The remaining *** samples were not analysed for particle size, and their texture characteristics are based on the field descriptions.

The methods of analysis currently used by SPAL are summarised in Appendix A.

5. SOIL CLASSIFICATION AND CHARACTERISTICS

As this is a large survey and includes many types of soils, the soil classification and soil characteristics are covered in this chapter. Soil correlations are covered separately in Chapter 6.

5.1 Soil classification in Bhutan

THIS MAY WELL REQUIRE TOTAL RE-WRITING BASED ON CURRENT ACTIONS ? ACTIVITY WITH SERIES

Soil classification was done in an ad hoc way in the early stages of SSU. Survey areas were treated separately, and sets of local soil classes were defined for each (see Reports SS1-8 and SS10-13 (SSU, 1998-2000)).

With increasing field experience, we have built up a preliminary outline of the soils of mid-latitude part Bhutan, and have formulated a provisional framework for their classification. The assumptions and procedures of the proposed system will be given in Technical Working Paper WP3 (SSU 2000).

The soils are classified into soil series, mostly on the basis of features that can be identified in the field. A few series are separated on chemical features. The field features used to define series are morphological (i.e. soil profile), parent material, landform and land use. The series are named after places at or near where profiles have been described and analysed. Only soils that have been seen are defined and named as series. We are not naming 'empty box' series for the future.

5.2 Soil series of Punakha arable lands

Table 5.1 summarises the overall structure of the classification and lists the soil series in the survey area. The first division is between soils that have been developed for chhushing, and those that have not. This is because the construction of flat irrigation terraces on slopes completely disrupts the layers (=horizons) of the natural soil profile. It buries natural topsoils and brings subsoil and weathered rock up to the surface. The cultivation of basin-irrigated rice further alters the natural soil by creating artificially waterlogged conditions in the upper layers for several months each year. Soils that have been used for chhushing therefore share many similarities, and are quite different from non-chhushing soils.

Tables 5.2 – 5.4 summarise further divisions according to the source rock type and kind of the soil parent materials. The source geological bedrock type is a criterion only for materials that have been transported locally, i.e. hill slope deposits and side valley alluvial fans. The alluvia in the main valleys are derived from a mixture of different geological formations in the High Himalaya and are not differentiated. The provisional differentiation of soil series on source bedrock may later turn out to be unnecessary. However it is retained for the present because some soil variation appears to be geologically determined.

Sections 5.3 – 5.9 outline the general characteristics of the soil series in the survey area. Although the survey concentrates on chhushing areas, the non-chhushing series are described first, as they are the 'natural' soils and it is easier to see how the chhushing soils have developed if their start-points are known.

More details can be obtained from the descriptions and analyses of the individual profiles.

The profiles for each series are summarised in Table 5.5, and their analyses are summarised in Table 5.6. The full data are obtainable from SSU on request.

Table 5.1 Overview of series classification of soils of Punakha arable lands

Landuse	***Non-Chhushing***					***Chhushing***		
PM type	***Residual + colluvial***		***Fan alluvium***		***Main river alluvium***	***Residual + colluvial***		***Fan al***
PM source - geological formation	***Thimphu***	***Chheka***	***Thimphu***	***Chheka***	***Un-differentiated***	***Thimphu***	***Chheka***	***Thimphu***
Series criteria	*Drainage, texture, colour & depth (see Table 5.3)*	*Drainage & texture (see Table 5.4)*	*Drainage & depth (see Table 5.3)*	*See Table 5.4*	*Landform & height above river (see Table 5.5)*	*Depth & colour (see Table 5.3)*	*See Table 5.4*	*Subsoil colour (see Table 5.3)*
Series	Thimphulem	Chhekalem	Ololem	Thongbji	Jimsa	Keylikha	Jarigang	Thara
	Yusipang	Khardung	Hongtsho		Dochhuka	Gumakha	Radhi	Yuewakha
	Bathpalathang	Chaling	Semtokha		Laku	Dompola	Panthang	Hebesa
	Kangma	Datong	Tsephu		Mendegang	Umtekha	Tsangkhar	**Kubji**
	Kanglung		Khuru		Chhuridho			Lungkha
	Norbugang							Botaka
	Laptsakha							
	Gyonchhuka							
	Walakha							
	Talo (10)	4	5	1	5	4	4	6

5.3 Non-chhushing soil series on Thimphu formation parent materials

Table 5.2 summarises the hill and fan soils derived from Thimphu Formation parent materials.

5.3.1 General relationships and differences between non-chhushing Thimphu series

Thimphulem series includes all of the poorly drained soils in declivities and minor drainage lines on hill slopes

Yusipang, Bathpalathang, Khangma and Kanglung series are well-drained, greyish or yellowish brown or reddish yellow hill soils of medium texture, derived from mixed gneiss, quartzite and intrusive granite colluvium on hill slopes. They are differentiated on the depth to weathered rock, and whether their subsoils are uniformly brightish coloured or whether they include darker horizons due to the burial of previous topsoils.

Norbugang, Laptsakha, Gyonchhuka and Walakha series are well drained, bright red hill soils derived from skarn, amphibolite and biotite gneiss of the Thimphu formation. Norbugang and Laptsakha series have heavy textured (clay loam, silty clay, or clay) subsoils, and are differentiated on whether they are shallower (Norbugang) or deeper (Laptsakha) than about 1m to weathered rock. The depth can overlap to allow for variation in the subsoil stone contents. Gyonchhuka (shallow) and Walakha (deep) series are the medium textured (mostly sandy clay loam and sandy clay) equivalents that are similar in colour and structure. Talo series is also derived from the skarn and related bedrocks. However it has a predominantly dark coloured subsoil due to indistinct buried topsoil(s). So far no shallow equivalent of Talo series has been seen.

Most of the alluvial fans have been developed for chhushing. The non-chhushing fan soils are not extensive and few were seen during the survey. They do not show the diversity that is noted in the chhushing fan soils (see 5.5 below). They are differentiated on subsoil drainage, between wet and gleyed (Ololem), imperfectly drained greyish brown and mottled (Hongtsho), and well drained brown or reddish yellow (Semtokha). Khuru series is for the inextensive non-chhushing soils on fan terraces.

5.3.2 Thimpulem series

This series includes all of the poorly drained soils in minor drainage lines and declivities on hills on the Thimphu formation. The total area covered is not large, but these soils are widely scattered as many small occurrences. These soils are variable, but the main feature in common are the damp or wet surface horizons, with gley matrix colours and distinct rust brown tubular mottling. The poor drainage persists throughout in some profiles, and the wetness appears to be fed by high watertable. However many of the subsoils are moist, rather than wet, and the main colour is brown rather than grey, although there are usually rusty or orange mottles. This means that the subsoils are better drained than the topsoils, and these soils qualify as surface water gleys or stagni-gleyic. They are mainly fed by shallow subsurface lateral seepage.

Soils of this series are formed in variable deposits and many have distinctly layered textural sequences. Some are quite shallow and grade to wet, soft, often silvery-looking (because of unweathered muscovite) weathered rock within 100 cm. These soils do not warrant separating into different series on depth, because of their limited extent.

No profiles in these soils were described or analysed during this survey but examples can be seen in the Yusipang (Profile Pd005 & Pd006 and Bathpalathang (Profile PKH020) reports (SSU Reports 1 & 2, 1998).

Table 5.2 Soil series derived from Thimphu Formation parent materials in Punakha

Non-Chhushing				***Chhushing***			
Residual & colluvial		***Fan alluvium***		***Residual & colluvial***		***Fan alluvium***	
Differentiating features	***Series***	**Differentiating features**	***Series***	**Differentiating features**	***Series***	**Differentiating features**	***Series***
Poorly drained hill soils	**Thimphulem**	Poorly drained fan soils	*Ololem*	Grey or brown loam subsoil, <110 cm deep	**Dompola**	Grey or brown loam subsoil, >110 cm deep, well drained	**Thara**
Well drained Y, RY, & BrY loam < 110 cm deep	*Yusipang*	Imperfectly drained fan soils	*Hongtsho*	Grey or brown loam subsoil, >90 cm deep, well drained at depth	*Kyelikha*	Grey or brown loam subsoil, >90 cm deep, imperfectly-poorly drained	**Hebesa**
Well drained Y, RY, & BrY loam > 90 cm deep	*Bathpalathang*	Well drained brown loam fan soils	*Semtokha*	Grey or brown loam subsoil, >90 cm deep, imperfectly drained at depth	Gumakha	Grey or brown loam subsoil, <110 cm deep to dense boulders or weathered rock	**Yuewakha**
Similar to Yusipang but with buried topsoil	*Khangma*	Well drained red clay - loam fan soils	**Tsephu**	Reddish brown loam – clay subsoil, >90 cm deep	*Umtekha*	Reddish brown loam subsoil, >90 cm deep	*Kubji*
Similar to Bathpalatahang but with buried topsoil	*Kanglung*	Fan terrace soils	**Khuru**			Grey or brown loam topsoil with thick subsoil layer of loamy sand or	**Lungkha**

						sand; well drained	
Bright red clay < 110 cm deep	*Norbugan g*					Grey or brown fine loam - clay subsoil, <110 cm deep, on fan terrace	**Botaka**
Bright red clay > 90 cm deep	*Laptsakha*						
Dark brown clay > 90 cm deep	*Talo*						
Bright red loam < 110 cm deep	*Gyonchhu ka*						
Bright red loam > 90 cm deep	*Walakha*						

5.3.3 Yusipang series

These soils are defined as having brightly coloured subsoil, and shallow sola, with weathered rock at less than about 1m. They are very extensive in mid-latitude Bhutan. However relatively few were seen during this survey because the hill soils examined are mostly on lower slopes where the colluvium is deep. The main occurrences in the survey area are on hill slopes in shallow the side valleys of Nyakalumpa Chhu and Shoshi Rong Chhu. For details of the profiles in these soils in the survey area, see Table 5.5. Further descriptions and analyses of soils of this series can be seen in the SSU reports for the Yusipang (Pd001, PH003, & PK002), Bathpalathang (PH010 & PK017) and Lingmutey Chhu (PH021, PH022, PK034, & PK038) surveys (SSU Reports 1a, 2a, & SS5a).

These soils have relatively light coloured topsoils, mostly greyish brown or brown. Textures are mostly sandy loam, and structures are crumb - subangular blocky. They grade into brown, yellowish brown, strong brown, or reddish yellow subsoils. These are of sandy loam to sandy clay texture, mostly sandy clay loam or heavy sandy loam. The subsoil has moderate strong subangular or angular blocky structures. The subsoils are moderately firm when moist. They may contain gneiss, quartz, and granitic stones, and fragments of soft, multi-coloured weathered rock. The subsoil grades to *in situ* weathered rock within 90-110 cm, but this is often soft enough to be rootable

These soils are slightly acid to neutral with pH (water) values in the range 5.7 – 7.1. They have moderate – low cation exchange capacities, in the range of 3-10 me%. The lower CEC's are more or less fully base saturated, but the base saturation of the soils with higher CEC's are below 50%. In most soils Ca^{++} *is the dominant cation, but* Mg^{++} *is at about parity in some horizons in Profile PK034. Organic carbon and total nitrogen contents are low – very low. Available P levels are very low, except in the topsoil of the one wetland rice profile (Profile PK041).*

5.3.4 Bathplathang series

This series is the deep equivalent of Yusipang. It is also defined as having brightly coloured subsoil, but with deep sola, with weathered rock at more than about 1m. These soils are also extensive in mid-latitude Bhutan. They are commoner than Yusipang in this survey area because the hill soils examined were most on lower slopes where deeper colluvium accumulates. The main occurrences in the survey area are also on hill slopes in shallow the side valleys of Nyakalumpa Chhu and Shoshi Rong Chhu. For details of profiles of these soils in the survey area, see Table 5.5. Further descriptions and analyses of this series can also be seen in the SSU reports for the Bathpalathang (PK016) and Lingmutey Chhu (PK037) surveys (SSU Reports 1a, 2a & 5a, 1998-9)

These soils have relatively light coloured topsoils, mostly greyish brown or brown. Textures are mostly sandy loam, and structures are crumb - subangular blocky. They grade into brown, yellowish brown, strong brown, or reddish yellow subsoils. These are of sandy loam to sandy clay texture, mostly sandy clay loam or heavy sandy loam. The subsoil has moderate strong subangular or angular blocky structures, which may have moderate or weak patchy clayskins on their faces. The subsoils are moderately firm when moist. They may contain gneiss and quartz, and a few granitic stones, and fragments of soft, multi-coloured weathered rock, but these are only few or common in the top 100 cm.

Some of these soils are deep because of stability, deep weathering and prolonged soil development. However many are formed in deep colluvium and are no more mature than the shallower soils of Yusipang series. Some colluvia have been deposited is several phases, giving variations in colour and texture that are due to layering of different deposits, not horizon development in a single material. Many of these soils are therefore correlated internationally as Inceptisols or Cambisols despite their depth.

*The soils ****Cation exchange capacities are moderate – low. They are nearly fully base-saturated, with* Ca^{++} *as the main exchangeable cation. Organic carbon, total N and available P are very low throughout. The single profile under old growth forest (PK037) has pH levels about one unit lower and is slightly acid (pH 6.0-6.5). Topsoil organic carbon and total nitrogen contents are moderate in this profile and higher than in the wetland soils, but available P is still very low. The higher organic matter contents in this profile give higher CEC levels, so that base saturations are low, at about 20%, throughout the subsoil.*

5.3.5 Khangma series

These are similar to soils of Yusipang series in depth, drainage, and texture. They differ in that the subsoils are darker. When seen in full pit profiles, it is clear that the dark colours are due to one or more buried topsoils. These soils are therefore formed in colluvium that has been deposited in several phases, with long enough intervals for topsoils with dark colours, high faunal activity, dense rooting and crumb structures to form before being buried. Multi-phase colluvial deposits are normally thick. This means that the shallow soils of Khangma series are less extensive than the deeper equivalents in Kanglung series.

For details of profiles of these soils in the survey area, see Table 5.5. Further description and analyses of another profile of this series, see report for the Khangma (PH035) survey (SSU Report 4a, 1999)

These soils have moderately dark coloured topsoils, mostly dark greyish brown or dark brown. Textures are loamy, usually sandy loam, and structures are crumb - subangular blocky. They grade into brown, yellowish brown, strong brown, or reddish yellow subsoils. These are of sandy loam to sandy clay texture, mostly sandy clay loam or heavy sandy loam. Below this the soil becomes darker again, often dark brown or dark grey. This buried topsoil is often open and porous and has crumb or compound blocky-breaking-to-crumb structure. It may still have the high root density of it former topsoil. Below that the soil becomes brighter coloured and has moderate strong subangular or angular blocky structures, which may have moderate or weak patchy clayskins on their faces. This horizon appears to be the subsoil of the original, buried profile. These horizons are moderately firm when moist, and usually contain gneiss and quartz, and a few granitic stones, and fragments of soft, multi-coloured weathered rock. By definition the soils of this series overlie weathered rock within 90-110 cm.

*The *****Cation exchange capacities are moderate – low. They are nearly fully base-saturated, with* Ca^{++} *as the main exchangeable cation. Organic carbon, total N and available P are very low throughout. The single profile under old growth forest (PK037) has pH levels about one unit lower and is slightly acid (pH 6.0-6.5). Topsoil organic carbon and total nitrogen contents are moderate in this profile and higher than in the wetland soils, but available P is still very low. The higher organic matter contents in this profile give higher CEC levels, so that base saturations are low, at about 20%, throughout the subsoil.*

5.3.6 Kanglung series

These are similar to soils of Bathpalathang series in depth, drainage, and texture. They differ in that the subsoils are darker, so that they are the deep equivalent of Khangma series. As in Khangma series, the dark colours are due to buried topsoil(s), and these soils are formed in colluvium that has been deposited in several phases, with long enough intervals for topsoils with dark colours, high faunal activity, dense rooting and crumb structures to develop before being buried. Multi-phase colluvial deposits are normally thick. This means that these deeper soils of Kanglung series are more extensive than their shallow equivalents in Khangma series. For details of profiles of these soils in the survey area, see Table 5.5. Further descriptions and analyses of profiles of this series can also be seen in the SSU reports for the Yusipang (PH002 & PK001), Bathpalathang (PK018) and Khangma (PC003, Pd012, Pd013, PH034,PK032, & PK047) surveys (SSU Reports 1a, 2a & 4a, 1998-9)

These soils have moderately dark coloured topsoils, mostly dark greyish brown or dark brown. Textures are loamy, usually sandy loam, and structures are crumb - subangular blocky. They grade into brown, yellowish brown, strong brown, or reddish yellow subsoils. These are of sandy loam to sandy clay texture, mostly sandy clay loam or heavy sandy loam. Below this the soil becomes darker again, often dark brown or dark grey. This buried topsoil is often open and porous and has crumb or compound blocky-breaking-to-crumb structure. Below that the soil becomes brighter coloured and has moderate strong subangular or angular blocky structures, which may have moderate or weak patchy clayskins on their faces. This horizon appears to be the subsoil of the original, buried profile. This sequence of buried topsoil and subsoil may be repeated again. Normally the topsoil characteristics are less pronounced in the lower horizons. However they are sometimes the lower topsoil may still be darker in some profiles. This is assumed to result from a situation, where the deep topsoil was at the surface fore a long time and was able to develop strongly, whereas the higher one was at the surface for only a short period before burial. The subsoils may contain a few gneiss, quartz, and granitic stones, and fragments of soft, multi-coloured weathered rock. By definition continuous weathered rock, usually gneiss, is below 90-110 cm, and is often much deeper, as colluvial deposits can be several metres thick on lower slopes.

The Cation exchange capacities are moderate – low. They are nearly fully base-saturated, with Ca^{++} as the main exchangeable cation. Organic carbon, total N and available P are very low throughout. The single profile under old growth forest (PK037) has pH levels about one unit lower and is slightly acid (pH 6.0-6.5). Topsoil organic carbon and total nitrogen contents are moderate in this profile and higher than in the wetland soils, but available P is still very low. The higher organic matter contents in this profile give higher CEC levels, so that base saturations are low, at about 20%, throughout the subsoil.

5.3.7 Norbugang series

The soils of this series are shallow red clays. They are quite extensive in the Talo-Norbugang-Punakha-Walakha area, and occur elsewhere where there is amphibolite, skarn or biotite gneiss. They are very noticeable on both sides of the lower valley of Shenga Rong Chhu, and occur as less extensive patches on the lower slope of valley of Po Chhu. For details of profiles of these soils in the survey area, see Table 5.5. Further descriptions and analyses of this series can also be seen in the SSU reports for the Yusipang (PH002,&PK001), Bathpalathang (PK016 & PK018) and Lingmutey Chhu (PH016, PH018, PH024, PH031, PK033, PK037) surveys (SSU Reports 1a, 2a & 5a, 1998-9)
Data from the * profiles in these soils were described and sampled during this survey are summarised in Appendix B.

The topsoils are mostly brown to dark reddish grey, and range in texture from sandy clay loam to clay. They have crumb or medium – fine subangular blocky structures. The topsoil consistence is fairly hard when dry, but friable when moist. The subsoil is usually fairly uniform bright red but yellowish red, dark red matrix colours also occur. A few of the subsoil horizons have faint grey and brown mottles, and many have distinct black ferri-manganiferous stains or soft concretions. Subsoil textures are clay loam, silty clay or clay. Subsoil structures are mostly moderate subangular or angular blocky, which may have moderate cutans on some faces. The cutans are usually brown, and appear to consist of mixed organic matter and some clay washed down from horizons above. By definition these soils overlie weathered rock within 100 cm. This is often white and powdery weathered skarn but is usually negative to HCl. Some weathered rock has bright orange, yellow and black colours, which are thought to come from the high iron contents released by the weathering of amphibolite or biotite.

A feature of these and the other reddish skarn/amphibolite soils is their erodibility. There are dendritic gully systems that have developed almost into badlands in places. The gully walls have only minor earth pillars (< 3 cm high), suggesting that rainsplash erosion is not important. Many overhangs, where soil structures have been undercut, have thick 'melted wax' coatings and small pseudo – stalactite features, where suspended clay has been deposited by evaporating water. This indicates that the clay is easily dispersed, and that the main agent initiating the erosion is surface runoff. The easy dispersion of the red clay is corroborated by the high suspended red clay load in the streams after rain, and in the thin films of red clay that is deposited by water on the wetland plots that are irrigated from channels originating in these soils.

These soils are chemically district from the other hill soils. They are of almost neutral reaction, with pH values mostly in the range 6.2 – 7.0. They are relatively well supplied with exchangeable bases, with TEB values in the range 6-10 me/100 g. The cation balance is quite variable. In some of these profiles Ca^{++} is the dominant exchangeable cation, with Ca: Mg ratios > 2.5 in all horizons (e.g. profile PH019). Such soils are probably derived from skarn. In other profiles Mg^{++} is the dominant exchangeable cation, with Ca:Mg ratios < 1, and as low as 0.3 in some horizons (see profile PH025). This may indicate a predominantly amphibolitic provenance. The cation exchange capacities of some of these soils are low, indicating mainly 1:1 aluminosilicate and sesquioxide clay minerals (e.g. Profile PH025). These low CEC's lead to high or total base saturations. Other profiles have moderate CEC's and therefore moderate base saturations, in the range 40-60% (e.g. profile PH042). Nearly all of these soils have low contents of organic carbon, total nitrogen and available P. The exception is the upper part of Profile PK044, which has moderate – high available P, possibly because of previous fertilizer applications, as this profile is sited in a terraced dryland field. The mechanical analyses of these soils are variable. The very high silt content (> 80%) in the second horizon of profile PH025 is attributed to strong aggregation by the sesquioxidic clays. This soil hand textured in the field, after vigorous kneading, as silty clay.

5.3.8 Laptsakha series

The soils of this series are deep red clays, and are the deep equivalent of Norbugang series. They are more extensive than Norbugang series in the Talo-Norbugang-Punakha-Walakha area, and in the red clay areas elsewhere in the survey area. * profiles in these soils were described and sampled during this survey .

The profile is similar to Norbugang but deeper. The topsoils are mostly brown to dark reddish grey, and range in texture from sandy clay loam to clay. They have crumb or medium – fine subangular blocky structures. The topsoil consistence is fairly hard when dry, but friable when moist. The subsoil is deep, fairly uniform bright red but yellowish red, dark red matrix colours also occur. A few of the subsoil horizons have faint grey and brown mottles, and many have distinct black ferri-manganiferous stains or soft concretions. Soils of this series have main subsoil textures of clay loam, silty clay or clay. Subsoil structures are mostly moderate subangular or angular blocky. There is often a horizon with clay and organic cutans, which tend to be better developed than in the shallower Norbugang soils. By definition these soils deeper than 100 cm to weathered rock. In fact many of these soils are much deeper than that, often with red clay extending to depths of more than three metres. The underlying saprolite is highly weathered and crumbly. Pale (skarn) colours predominate but there are also bright orange, yellow and black colours, which are thought to come from amphibolite or biotite.

The dendritic gullies are more pronounced in these deeper red clays.

These soils are chemically district from the other hill soils. They are of almost neutral reaction, with pH values mostly in the range 6.2 – 7.0. They are relatively well supplied with exchangeable bases, with TEB values in the range 6-10 me/100 g. The cation balance is quite variable. In some of these profiles Ca^{++} is the dominant exchangeable cation, with Ca: Mg ratios > 2.5 in all horizons (e.g. profile PH019). Such soils are probably derived from skarn. In other profiles Mg^{++} is the dominant exchangeable cation, with Ca:Mg ratios < 1, and as low as 0.3 in some horizons (see profile PH025). This may indicate a predominantly amphibolitic provenance. The cation exchange capacities of some of these soils are low, indicating mainly 1:1 aluminosilicate and sesquioxide clay minerals (e.g. Profile PH025). These low CEC's lead to high or total base saturations. Other profiles have moderate CEC's and therefore moderate base saturations, in the range 40-60% (e.g. profile PH042). Nearly all of these soils have low contents of organic carbon, total nitrogen and available P. The exception is the upper part of Profile PK044, which has moderate – high available P, possibly because of previous fertilizer applications, as this profile is sited in a terraced dryland field. The mechanical analyses of these soils are variable. The very high silt content (> 80%) in the second horizon of profile PH025 is attributed to strong aggregation by the sesquioxidic clays. This soil hand textured in the field, after vigorous kneading, as silty clay.

5.3.9 Gyonchhuka series

The soils of this series are shallow red loams. They are the medium textured equivalent of Norbugang series. They are also moderately extensive in the Talo-Norbugang-Punakha-Walakha area, and other places where there is amphibolite, skarn or biotite gneiss. * profiles in these soils were described and sampled during this survey .

The topsoils are mostly brown to dark reddish grey, and range in texture from sandy loam to sandy clay. They have crumb or medium – fine subangular blocky structures. The topsoil consistence is fairly hard when dry, but friable when moist. The subsoil is just as bright coloured as in the clays, and is usually fairly uniform red, but yellowish red, and dark red matrix colours also occur. As in the clays, there may be a few faint grey and brown mottles, but black ferri-manganiferous stains are generally less pronounced. Subsoil textures are sandy clay loam, silty clay loam or sandy clay. Subsoil structures are mostly moderate subangular or angular blocky, which may have moderate brown mixed cutans on some faces. By definition these soils overlie weathered rock within 100 cm. As in the clays this is often white and powdery weathered skarn, with some patches of bright orange, yellow and black colours from amphibolite or biotite.

No difference in susceptibility to gullying has been noted between these soils and the clays.

These soils are chemically district from the other hill soils. They are of almost neutral reaction, with pH values mostly in the range 6.2 – 7.0. They are relatively well supplied with exchangeable bases, with TEB values in the range 6-10 me/100 g. The cation balance is quite variable. In some of these profiles Ca^{++} is the dominant exchangeable cation, with Ca: Mg ratios > 2.5 *in all horizons (e.g. profile PH019). Such soils are probably derived from skarn. In other profiles* Mg^{++} *is the dominant exchangeable cation, with Ca:Mg ratios < 1, and as low as 0.3 in some horizons (see profile PH025). This may indicate a predominantly amphibolitic provenance. The cation exchange capacities of some of these soils are low, indicating mainly 1:1 aluminosilicate and sesquioxide clay minerals (e.g. Profile PH025). These low CEC's lead to high or total base saturations. Other profiles have moderate CEC's and therefore moderate base saturations, in the range 40-60% (e.g. profile PH042). Nearly all of these soils have low contents of organic carbon, total nitrogen and available P. The exception is the upper part of Profile PK044, which has moderate – high available P, possibly because of previous fertilizer applications, as this profile is sited in a terraced dryland field. The mechanical analyses of these soils are variable. The very high silt content (> 80%) in the second horizon of profile PH025 is attributed to strong aggregation by the sesquioxidic clays. This soil hand textured in the field, after vigorous kneading, as silty clay.*

5.3.10 Walakha series

The soils of this series are deep red loam, and are the deep equivalent of Gyonchhuka series, and the medium textured equivalent of Laptsakha series. As in the clays the deeper loams are more extensive than the shallow Gyonchhuka series. * profiles in these soils were described and sampled during this survey .

The profile is similar to Gyonchhuka but deeper. The topsoils are mostly brown to dark reddish grey, and range in texture from sandy loam to sandy clay. They have crumb or medium – fine subangular blocky structures. The topsoil consistence is fairly hard when dry, but friable when moist. The subsoil is bright red in the clays. As in the clays, there may be a few faint grey and brown mottles, but black ferri-manganiferous stains are generally less pronounced. Subsoil textures are sandy clay loam, silty clay loam or sandy clay. Subsoil structures are mostly moderate subangular or angular blocky, which may have moderate brown mixed cutans on some faces. By definition these soils deeper than 100 cm to weathered rock. Like the Laptsakha clays many of these soils are much deeper and may extend to more than three metres. The crumbly underlying saprolite is predominantly pale but there are also bright orange, yellow and black colours.

These soils are similar to the other red soils in that they are susceptible to deep gullying.

These soils are chemically district from the other hill soils. They are of almost neutral reaction, with pH values mostly in the range 6.2 – 7.0. They are relatively well supplied with exchangeable bases, with TEB values in the range 6-10 me/100 g. The cation balance is quite variable. In some of these profiles Ca^{++} *is the dominant exchangeable cation, with Ca: Mg ratios > 2.5 in all horizons (e.g. profile PH019). Such soils are probably derived from skarn. In other profiles* Mg^{++} *is the dominant exchangeable cation, with Ca:Mg ratios < 1, and as low as 0.3 in some horizons (see profile PH025). This may indicate a predominantly amphibolitic provenance. The cation exchange capacities of some of these soils are low, indicating mainly 1:1 aluminosilicate and sesquioxide clay minerals (e.g. Profile PH025). These low CEC's lead to high or total base saturations. Other profiles have moderate CEC's and therefore moderate base saturations, in the range 40-60% (e.g. profile PH042). Nearly all of these soils have low contents of organic carbon, total nitrogen and available P. The exception is the upper part of Profile PK044, which has moderate – high available P, possibly because of previous fertilizer applications, as this profile is sited in a terraced dryland field. The mechanical analyses of these soils are variable. The very high silt content (> 80%) in the second horizon of profile PH025 is attributed to strong aggregation by the sesquioxidic clays. This soil hand textured in the field, after vigorous kneading, as silty clay.*

5.3.11 Talo series

Colluviation is less apparent in the red soils than in the brown and grey gneissic soils. Nonetheless there are some soils in this area with dark coloured subsoils, which appear to be due to former topsoils, which have been buried and mixed by hillwash. These soils of Talo series are finer textured equivalents of Kanglung series, although textures are variable due to colluvial layering. 2 profiles in this series has been described in detail and sampled (PC048 & Pd116).

These soils have dark grey humic topsoils, with a weak root-bound crumb structure and friable consistence. In profile Pd116 the subsoil is layered dark brown or brown down to at least 1.5 m. Subsoil textures in this profile range from sandy loam to sandy clay loam, which is on the light side. It is friable and porous throughout and it is therefore well rooted to the base. In the other (PC048) the buried subsoil is separated from the current surface by a metre of strong brown firm blocky soil, the texture of which is predominantly silty clay and clay. This is much less freely rooted than the subsoil of Pd116.

Organic C and total nitrogen contents are high throughout, but available P is low. The high contents of organic matter give high contents of exchangeable cations, especially $Ca^{++,}$ *in the upper horizons. However, the contents of exchangeable cations drop to low levels in the lower subsoil, and base saturations are below 10%. These soils are more acid than the red clays, with pH (water) values mostly in the range 5.5 - 6.*

5.3.12 Ololem series

This series accommodate all of the really poorly drained soils on the fans. They occur in narrow strips along minor drainage lines on the fans. No profiles were described in detail or sampled in these soils during this survey but there are typical profiles in the Yusipang report (Profiles P**** in SSU report 1a, 1998).

These soils have wet surface mucky or humic surface layers. The upper layer of the underlying mineral soils has gley matrix colours and distinct rust brown tubular mottling. The drainage may be poor throughout the profile. However in some profiles, the subsoils are moist, rather than wet, and the main colour is brown rather than grey, although usually still with rusty or orange mottles. Textures are variable according the layering of the fan, but are normally in the range sandy loam – sandy clay. The fan deposits are deep but often contain stones. These are often of mixed lithology and degrees of weathering, and are randomly oriented. In some profiles the stones are moderately concentrated in poorly defined layers, but they are randomly distributed in others.

5.3.13 Hongtsho series

This series includes the imperfectly drained soils on the fans. These soils are not extensive and no profiles were described in detail or sampled in these soils during this survey but there are typical profiles in the Yusipang report (Profiles P**** in SSU Report 1a, 1998).

The topsoils have grey or brownish grey matrix colours and distinct rust brown tubular mottling. The subsoil colours are greyish brown or brownish grey, with rusty or orange mottles. As with Ololem series, the textures are variable may be weakly layered. Stones are randomly oriented and mixed.

5.3.14 Semtokha series

This series includes the well drained non-chhushing soils on alluvial fans derived from the main gneiss and quartzite rocks of the Thimphu formation. It is thought there may also be non-chhushing fan soils with redder and finer texture subsoil that are derived mainly from the skarn and related rocks

in the Thimphu. However no such soils were seen during this survey, and so far no series has been defined for them.

These soils are not extensive in the survey area and no profiles were described inn detail or sampled during this survey. However there is one described and analysed profile (PK004) in the Yusipang report (SSU Report 1a, 1998).

The Semtokha series profile typically has a brown, friable, crumb structured topsoil. The subsoil is yellowish – strong brown with few, if any mottles. The structure is moderate subangular blocky, with few if, any clayskins or other types of cutans. The textures vary within the range, sandy loam – sandy clay. The textural horizonation results from the alluvial deposition and clay translocation is not apparent. There are variable contents of mainly non-layered and randomly oriented stones.

There is one sampled profile in these soils (PK004). The analyses show this soil to be chemically district from most others on the Centre. The soil of nearly neutral pH (6.5-7) and of very high base saturation (above 75% in all samples) throughout the profile. Topsoil organic carbon and total nitrogen contents are low to moderate, but available P (35 ppm) and K and exchangeable K (1.0 me%) are high. As expected from the bright colours, organic matter levels are low in the subsoil horizons.

5.3.15 Tsephu series

This series is for non-chhushing soils with redder and finer texture subsoil that are formed in fan alluvium derived mainly from skarn and related rocks of the Thimphu formation. They are the reddish, skarn-derived equivalents of Semtokha series and the non-chhushing equivalents of Kubji series

As most of the reddish fan soils have been used for chhushing, these soils are not extensive in the survey area and occur mainly in small uncultivated patches on the lower Shengana fan, downstream of Lungkha. N*o* ***profiles were described in detail or sampled*** during this survey.

The Tsephu series profile typically has a brownish, friable, crumb structured topsoil. The subsoil is strong – reddish brown with few, if any mottles. The structure is moderate subangular blocky, with few if, any clayskins or other types of cutans. The textures vary within the range from sandy loam to clay loam. The textures are generally heavier than in Semtokha series, due to the contribution from skarn and/or amphibolite to the parent material. The textural horizonation results from the alluvial deposition and clay translocation is not apparent. There are some mainly non-layered and randomly oriented stones.

5.3.16 Khuru series

This series is for an very inextensive group of soils on the small fan terraces cut in to the sided of alluvial fan along streams. No profiles were described or analysed in these soils during this survey.

Their profiles are similar to Semtokha series profile except that they tend to texturally more layered, a expected from being deposited by modern stream rather than chaotic and turbulent glacial melt water.

They have brown, friable, crumb structured topsoils. The subsoil is yellowish or greyish brown with few, if any mottles. The structure is moderate subangular blocky, with few if, any clayskins or other types of cutans. The textures vary within the range, sandy loam – sandy clay, and show moderate horizonation due to their alluvial deposition. There may be some stones, which also tend to be layered.

5.4 Non-chhushing soil series on Chekha formation parent materials

5.4.1 General relationships and differences between non-chhushing Chekha series

Chekhalem series includes all of the poorly drained Chekha soils in declivities and minor drainage lines on hill slopes

Khardung and Chaling series are deep well-drained brown, reddish yellow and hill soils of light and medium texture, developed in colluvium, mainly derived from quartzite and granite with subordinate phyllite, on hill slopes. They are differentiated on texture. Dado series includes shallow coarse textured soils, and is the shallow equivalent of Kardung series. No shallow medium textured equivalent of Chaling series was seen during the survey.

All of the soils seen on Chekha-derived alluvial fans were under chhushing at the time of our survey, so no non-chhushing series are defined.

This group of series is summarised in Table 5.3

Table 5.3 Soil series derived from Chhekha Formation parent materials in Punakha

Non-Chhushing				***Chhushing***			
Residual & colluvial		***Fan alluvium***		***Residual & colluvial***		***Fan alluvium***	
Differentiating features	***Series***	**Differentiating features**	***Series***	**Differentiating features**	***Series***	**Differentiating features**	***Series***
Poorly drained hill soils	**Chhekhal em**	Well drained fan soils	*Thongbji*	Grey or brown sandy loam – sandy clay loam subsoil	**Jarigang**	Grey or brown loam subsoil, <110 cm deep; well drained	**Shengana**
Well drained Y, RY, & BrY coarse loam, > 90cm deep	*Khardung*			Grey or brown loam –clay subsoil	**Radhi**	Grey or brown loam subsoil, <110 cm deep; imperfectly drained	Gangkha
Well drained Y, RY, & BrY coarse loam, < 110cm deep	Datong			Red loam subsoil, <110 cm deep	*Pangthang*		
Well drained Y, RY, & BrY fine loam & clay, > 90cm deep	*Chaling*			Red loam subsoil, >90 cm deep	*Tsangkhar*		

5.4.2 Chekhalem series

This series includes all of the poorly drained soils in minor drainage lines and declivities on hills on the Chekha formation. As we included only limited areas of Chekha non-chhushing in the survey area, the total area covered is small, scattered as small occurrences. These soils are similar in morphology to those of Thimphulem series, with damp or wet surface horizons, with gley matrix colours and distinct rust brown tubular mottling. The poor drainage persist throughout the profile, and the wetness appears to be fed by locally high groundwater. However as in Thimphulem, many of the subsoils are brown rather than grey, and not as wet as the topsoil. This means that these soils are fed by shallow subsurface lateral seepage and qualify as surface water gleys or stagnogleys

Soils of this series are formed in variable deposits and many have distinctly layered textural sequences, but textures tend to be coarser than in Thimphulem series, with layers of coarse and medium sand.

No profiles in these soils were described in detail or analysed during this survey.

5.4.3 Khardung series

This series includes the deep, well-drained, and coarse textured soils. They are thought to be derived from the quartzite and granite components of the Chekha. The soil seen are mostly under broadleaf forest, that is used for fuelwood and timber cutting, grazing, and sokshing. * profiles in these soils has been described in detail and sampled for analysis during this survey, and examples of similar soils can be seen in the Lingmutey Chhu (PH029) and Radhi (profiles P***) (SSU Reports 6a and 5a, 1999).

The topsoils are fairly pale coloured, loose, open, porous crumb-structured light loamy sands or sandy loam. By definition the subsoil is sandy loam or coarser in texture. It is friable, strong brown or reddish yellow, and weakly blocky structured. In the lower subsoil, the colour brightens to yellowish red, and the texture becomes slightly finer to heavy sandy loam. Consistence usually remains friable to 160 cm+. Augering up the ridge confirmed the depth, friability, bright orange-yellow colours, and coarse textures of these soils.

The sampled profile has a moderate organic C content in the topsoil, together with moderate total N and high available P. The organic matter content gives the topsoil a moderate cation exchange capacity, but the CEC's are low in the subsoil. These soils have low base saturations, in the range 15-25%. Ca^{++} and Mg^{++} are coequal components of the low total exchangeable bases. The low base saturation is paralleled by slight acidity, with pH (water) values just under 6 in all horizons.

5.4.4 Chaling series

This series is the medium texture equivalent of Khardung series, and are thought to form in colluvium with moderate contents of phyllitic material. In the survey area, they are less extensive than the coarser textured soils of Khardung series. * profiles were described in detail and sampled for analysis.

These soils have is dark brown or greyish brown topsoils very fine sandy or silty loam textures and medium subangular blocky structures. The subsoil is yellowish or strong brown, or reddish yellow sandy clay loam. Some subsoils have yellow, black and orange but no grey mottles and appears to be well drained. Subsoil structures are coarse subangular blocky, sometimes with weak discontinuous clayskins.

These soils are neutral or slightly acid. In one profile the pH is highest at the surface and decreases in the subsoil, but the trend is reversed in the other two. However the differences are not very marked in any of them. Base saturations are high (>50%) throughout, except in the one topsoil in which the pH has been raised by rice cultivation. The high base status is mostly due to moderate contents of exchangeable Ca. Organic carbon, total N and available P are very low in all profiles. The contents of exchangeable K are low - moderate but available K is low.

5.4.5 Dado series

This series includes the shallow, well-drained, and coarse textured soils derived from the quartzite, pegmatite and granite components of the Chekha formation. The soil(s) seen are mostly under broadleaf forest, which is used for fuelwood and timber cutting, grazing, and sokshing. * profiles in these soils has been described in detail and sampled for analysis during this survey.

The topsoils are fairly pale coloured, loose, open, porous crumb-structured light loamy sands or sandy loam. By definition the subsoil is sandy loam or coarser in texture. It is friable, strong brown or reddish yellow, and weakly blocky structured. In deeper profiles the lower subsoil, the texture may become slightly finer to heavy sandy loam, but consistence remains friable to the weathered rock. By definition these soils are less than 110 cm deep to weathered rock, some a shallow as 30 cm. The waethered rock is mostly pale coarse granite or pegmatite.

The sampled profile(s) has a moderate organic C content in the topsoil, together with moderate total N and high available P. The organic matter content gives the topsoil a moderate cation exchange capacity, but the CEC's are low in the subsoil. These soils have low base saturations, in the range 15-25%. Ca^{++} and Mg^{++} are coequal components of the low total exchangeable bases. The low base saturation is paralleled by slight acidity, with pH (water) values just under 6 in all horizons.

5.5 Non-chhushing soil series on major river alluvia

5.5.1 General relationships and differences between non-chhushing series on main river alluvia

The long distance alluvia that have been transported and deposited by the main rivers are derived from a range of different source bedrock types. Therefore no attempt is made to separate their soils according to specific geological formations. The soils are grouped according to the height of the alluvial parent material above the current level of the rivers, as summarised in Table 5.4.

Most of the alluvial soils along the rivers have been developed for chhushing, and the areas of the non-chhushing series are limited.

The general pattern in the alluvial soils is for stone-free sandy or silty loam upper horizons to overlie a bouldery layer in the subsoil. The bouldery layer tends at or very close to the surface in the young soils on the floodplain and low terraces, and at depths of up to several metres in the older deposits on high terraces. This could be due to differences in the hydrological and sedimentation regimes in the river at different times. An alternative explanation is that the alluvia were quite similar when deposited but the older deposits have been exposed longer and therefore have accumulated thicker overlying layers of windblown silt and fine sand. The differences are not explicable in this way unless the deposits are old or the rate of aeolian deposition was high. We lack definite data on either of these at present.

5.5.2 Jimsa series

This series is for raw and undeveloped soils on the banks and floodplain of the main rivers. They are less than 3 m above the usual summer river level, and may be inundated in exceptional floods. They are higher above the low water levels in winter and become quite dry. Where there is easy vehicle access, these soils are excavated and trucked for building sand. There is no profile development, and the soil consists of loose, white, fine sand, or boulder beds, or sandy boulders. It is similar to the material exposed in the current riverbed at low water levels. On some higher parts of the floodplain, the sandy surface soil is bound together by sward of low grasses. Where overgrazing or vehicles break through this mat, the sand underneath is easily disturbed and the finer fractions may be blown by wind.

There are no described or sampled profiles in these soils.

5.5.3 Dochuka series

This series is for the non-chhushing soils on the low terraces. They are at less than 10 m above the current river level. Very little of this land is not used for chhushing and these soils occur in a few small scattered patches. There are no described and sampled profiles for this series.

The topsoil is dark grey, brown or greyish brown fine sandy or silty loam. It has weak fine subangular blocky or crumb structures, and is friable when moist. The upper subsoil is slightly lighter in colour, but of similar texture. The structure is weak medium subangular blocky and the consistence may be friable. However in some soils the upper subsoil is very firm. At depths ranging from 30 to 80 cm, there is a marked change to the lower subsoil, which is white or very pale brown pale fine or medium sand or loamy sand. There may be thin lenses or finer material, usually silt or silty loan. This horizon continues down to bouldery and at depths between 50 and 200 cm.

5.5.4 Laku series

This series is for the non-chhushing soils on the middle terraces, which are at heights of between 15 and 30 m above the current river level. Most of this land is used for chhushing so that these soils are not extensive. There are ** described and sampled profiles for this series (see Table 5.2).

The topsoil is dark grey, brown or greyish brown fine sandy or silty loam. It has weak fine subangular blocky or crumb structures, and is friable when moist. The subsoil is lighter in colour, but of similar texture or slightly finer textures, commonly sandy or silty clay loam. The structure is weak-moderate medium subangular blocky and the consistence is usually slightly form when moist. The lower subsoils may have lenses of sand, loamy sand, silt or silty loam, usually below 1 m. Road cuttings show that these soil may have beds of boulders or gravel but these are usually below 2 m deep, and are not found in the top metre.

5.5.5 Mendegang series

This series is for the non-chhushing soils on the terraces at heights of 35 – 45 m above the current river level. These are the highest unequivocal river terraces seen in the survey ares. However there are terraces at considerably greater heights in the Bajo-Wangdi area downstream. Most of this land is used for chhushing so that these soils are not extensive. There are ** described and sampled profiles for this series (see Table 5.2).

The profile morphology of this series is very similar to that of Laku series. As in Laku, the topsoil is dark grey, brown or greyish brown fine sandy or silty loam, with weak fine subangular blocky or crumb structures, and is friable when moist. The subsoil is lighter in colour, but of similar texture or slightly finer textures, commonly sandy or silty clay loam. The structure is weak-moderate medium subangular blocky and the consistence is usually slightly form when moist. The main difference from Laku is in the lower subsoil. In soils of Mendegang series there are lenses of sand, loamy sand, silt or silty loam, usually below 1 m but these are deeper and less frequent than in Laku series . Road cuttings show that there may be beds of boulders or gravel, but these are always below 2 m deep.

5.5.6 Chhuridho series

This series accommodates the bouldery soils on the steep connecting slopes between the floodplain and the different levels of terraces. These soils are distinct from the other terrace soils in that they have rounded boulders sticking at the surface or at shallow depths. The profiles are simple, with dark brown sandy or silty loam or sandy clay loam or silty clay loam overlying a shallow boulder bed. In places the boulders actually protrude from the surface.

Soils of this type have been mapped in some very detailed surveys in Bhutan (SSU Reports 2a and 3a, 1998). However they occur as such narrow strips along breaks of slopes between terraces that they are unmappable in semi-detailed surveys such as this. There are no described or sampled profiles of this series for this survey but there is one from a similar soil in a related series in the Chamkar valley in East Central Bhutan (Profile PH008 in SSUP Report 2a, 1998).

5.6 Chhusing Soil Series

The soils that have been disturbed by the creation of flat terraces on naturally sloping land and have had their morphologies altered by the seasonal waterlogging and intensive cultivation associated with wet rice cultivation, are classified as separate series. It is often possible to deduce the original pre-chhushing soil from subsoil characteristics and topographic location. However the soils have usually been changed so much that they should be classified separately. The main changes due to chhushing are:

1. Burial of original topsoil on front parts of terrace.
2. Exposure of subsoil or weathered rock on rear parts of terrace
3. Mixture of original horizons.
4. Addition of extra silt and clay to new topsoil as suspended material in irrigation water.
5. Addition of reddish coloured sediment when irrigation water originates in skarn red clay hills.
6. Replacement of crumb or fine blocky structures in topsoils with medium or, occasionally, coarse blocks.
7. Development of soil capping at surface.
    8. Change of topsoil matrix colours to grey or greyish.
    9. Development of tubular reddish brown and blotchy orange mottles in topsoil.

10 Increased firmness (and hardness when dry) of topsoil consistence.
11 Increased greyness of matrix colours in upper subsoil.
12 Formation of blackish ferri-manganiferous stains and occasional soft concretions in subsoil, especially upper subsoil.
13 Depletion of topsoil organic matter, Organic C and Total N.
14 Raising of soil pH, exchangeable Ca and/or Mg, total exchangeable bases, and base saturation if irrigation water has crossed calcareous outcrops
15 Neutral or acid irrigation water reduces pH, exchangeable Ca and/or Mg, total exchangeable bases, and base saturation.

5.7 Chhushing soil series on Thimphu formation parent materials

5.7.1 Relationships between Thimphu chhushing soil series

These are the chhushing soils formed on residual, colluvial and fan alluvial fan parent materials derived from the Thimphu Formation. They are the chhushing equivalents of the series in Section 5.3, as summarised in Table 5.2.

The hill soils are divided into three series. Domphola and Kyelikha series are well drained soils with grey loam topsoils over brown and greyish brown loamy subsoils. They are separated into shallow Domphola and deep Kyelikha series according to whether they are less or more than about 100 cm deep to weathered gneiss. Gumakha series is similar to Kyeliha except that the subsoil is imperfectly drained. and has wet lower subsoils. No shallow equivalent of this series was seen in this survey. Umtekha series has a brownish fine loamy topsoil over a reddish brown fine loamy or clay subsoil. All of the soils seen of this kind are deeper than about 100 cm, so no shallow series has been defined.

The alluvial fans derived from the rocks of the Thimphu formation vary between catchments, so that different combinations of soils series predominated in the main different side valleys. Two series are defined for the Thimphu chhushing soils on the main fan of Nyakalumpa Chhu. In Thara series the lower subsoil below the effects of the chhushing is grey and brown loam. These develop in fan alluvium that is mainly derived from the gneiss, quartzite and other felsic components of the Thimphu formation. The lower subsoils in Kubji series are reddish brown or red, and this series develops in alluvium mainly derived from the skarn/amphibolite components of the red hills nearby. The fan deposits in Shoshi Rong Chhu are quite bouldery and give rise to the stony grey and brown soils of Yuewakha series. In the minor fans along the valley of Mo Chhu there are several patches of soils that are similar to Thara series, except that the lower subsoils are imperfectly or poorly drained. These are named Hebesa series. A well drained chhushing brownish fan soil but with thick sandy layers in the subsoil has been designated as Lunghka series.

As well as the fans in the valley bottoms, there are remnants of an older fan in the Nawakha-Jangwakha area in the northeastern corner of the survey area.

5.7.2 Domphola series

The soils of this series are of limited importance for chhushing in the survey area, because the deeper soils of Kyelikha series predominate on the lower slopes of the hills. There are * profiles described in detail and sampled for this series in the survey area. In addition there are data for one profile in the Lingmutey Chhu survey area (Profile PK041 in SSU Report 5a, 2000).

These are well drained soils. They have light coloured topsoils when dry, mostly light grey, greyish brown or pale brown, and have orange and reddish brown mottles. Textures are mostly sandy loam, and structures are subangular blocky, with platy structures in the upper few centimetres in some profiles. They grade into grey or greyish, yellowish, or strong brown subsoils, with reddish brown mottles, and black FeMn stains/soft concretions. These are of sandy loam to sandy clay texture, mostly sandy clay loam or heavy sandy loam. The subsoil has a moderate strong subangular or angular blocky structure. It is moderately firm when moist. It usually contains quartz, and gneiss stones, and fragments of weathered rock. The softer pieces have weathered to red, yellow, orange and grey colours, which give the soil a mottled appearance, although the profile drainage is good. By the series definition the subsoil grades into weathered rock at depths of less than about 1m. The rock is usually soft enough to be hand textured, as sandy loam or sandy clay loam. The depth criteria are interpreted flexibly, with Domphola soils extending to 100 cm if the subsoil contains many stones.

These soils are slightly acid to neutral with pH (water) values in the range 5.7 – 7.1. They have moderate – low cation exchange capacities, in the range of 3-10 me%. The lower CEC's are more or less fully base saturated, but the base saturation of the soils with higher CEC's are below 50%. In most soils Ca^{++} is the dominant cation. Organic carbon and total nitrogen contents are low – very low. Available P levels are very low, except in the topsoil of the one wetland rice profile (Profile PK041).

5.7.3 Kyelikha series

This series is for the deeper well drained grey loam chhushing hill soils. They are more extensive than the shallower Domphola soils on lower slopes. * profiles of this series were described in detail and sampled for analysis during this survey. Other profiles of this series are given in the Lingmutey Chhu report (see profiles PH016, PH018, PH024, PH031 and PK033 in SSU Report 5a, 1999).

Morphologically the soils of this series are similar to those of Domphola series However, as well as being deeper, they tend to have more complex horizonation, because of polyphasic deposition of the thicker colluvium.

They have grey brownish grey, hard (when dry) blocky topsoils, with textures in the range sandy loam – sandy clay, with heavy sandy loam and sandy clay loam predominant. The subsoils have variable brownish colours, commonly with orange, red and dark mottles. Greyish brown and reddish yellow subsoil horizons also occur. Subsoil textures tend to be slightly finer than in the topsoil, but vary rather erratically, ranging from gritty loam to silty clay loam, according to the colluvial layering. Subsoil structures are moderate subangular blocky, often with weak and patchy cutans. By definition these soils are more than about 100 cm deep to weathered rock, but stone free soils as shallow as 90 cm can be interpreted as Kyelikha.

These soils are neutral or slightly alkaline (with from pH (water) values ranging from 6.5 to 8). Cation exchange capacities are moderate – low. They are nearly fully base-saturated, with Ca^{++} as the main exchangeable cation. Organic carbon, total N and available P are very low throughout.

5.7.4 Gumakha series

This series is for imperfectly drained, grey, loam, chhushing soils on hill slopes. They are less extensive than the well drained Kyeikha soils. * profiles of this series were described in detail and sampled for analysis during this survey.

Morphologically the upper parts of the profiles of this series are similar to those of Domphola and Kyelikha series However, the lower subsoils are wet and gleyed with grey colours and rust mottles.

They have grey brownish grey, hard (when dry) blocky topsoils, with textures in the range sandy loam – sandy clay, with heavy sandy loam and sandy clay loam predominant. The upper subsoils are moist and have variable brownish colours, commonly with orange, red and dark mottles. The lower subsoils are wet and have grey, rather than brownish grey, matrix colours. Their mottles are reddish brown and hydromorphic, rather than due to weathered patches. Subsoil textures tend to be slightly finer than in the topsoil, but vary rather erratically, ranging from gritty loam to silty clay loam, according to the colluvial layering. Structures in the upper subsoil are moderate subangular blocky, often with weak and patchy cutans, but they are weaker in the lower subsoil. As in Kyelikha series, these soils are more than about 100 cm deep to weathered rock by definition, but stone- free soils as shallow as 90 cm can be included.

These soils are neutral or slightly alkaline (with from pH (water) values ranging from 6.5 to 8). Cation exchange capacities are moderate – low. They are nearly fully base-saturated, with Ca^{++} *as the main exchangeable cation. Organic carbon, total N and available P are very low throughout.*

5.7.5 Umtekha series

This series is for the hill chhushing soils that are derived from the skarn/amphibolite components of the Thimphu formation. They are characterised by the reddish colours in their lower subsoils, below the effects of the most intense chhushing effects. They are inherited from the pre-chhushing soils. This series is the chhushing equivalent of Laptsakha and Walakha series. No chhushing soils of this type shallower than 100 cm to weathered rock were seen in this survey, so no chhushing equivalent of Norbugang and Gyonchhuka series is needed. At present the fine loamy soils are include together in this series. This is inconsistent with the non-chhushing soils, which are divided on texture. This suggests that Umtekha should also be split.

These soils are widespread in the Talo-Walakha-Norbugang area. * profiles were described and sampled during this survey. In addition there are four profiles of this series are described in detail and sampled in the Lingmutey Chhu report (see profile s PH015, PH023, PH028 and PK043 in SSU Report 5a, 1999).

The dominant feature of these soils is the distinct colour boundary, with brown or greyish upper layers over redder deep subsoils. The topsoil is pale brown-light grey, hard, cloddy, sandy loam-sandy clay loam. At the base of the chhushing layer there is often a diffuse layer of black manganiferous mottles and very soft concretions. Below that the colours in the upper subsoils are predominately brown, but greyish and strong browns also occur. Textures are similar to the topsoil, in the sandy loam-sandy clay loam range. Structures are moderate angular - subangular blocky, sometimes with weak discontinuous cutans. At depths varying between 40 and 100 cm, there is a distinct change. The lower subsoil is red, reddish brown, or yellowish red. In some profiles it has higher clay contents. The structure is similarly blocky to the brown horizon above, but is more angular. Textures vary from sandy clay loam to clay. In none of the profile seen in these soils was weathered rock encountered, up to depths of 1.** m+. There are a few stones, but these are more common in the upper brown layers than in the red lower subsoil. They are mostly fragments of quartz or gneiss.

Most of these soils are of about neutral pH. In one of them (PH028) the pH (water) *increases by over one unit to the red subsoil, which is slightly alkaline. In two of the analysed soils, the moderate CEC's are wholly base-saturated, with Ca^{++} as the main cation. In another (PK043), the base saturation levels are low (< 35%) and Mg^{++} is the dominant cation. It is assumed that amphibolite is an important component in the parent material of this profile. Organic carbon and total N contents are very low in all horizons of the forested profile (PK043), but this profile has erratically high available P contents in two subsoil horizons. Organic carbon, total nitrogen and available P are low throughout in the cultivated profiles.*

5.7.6 Nawakha series

This soil occurs on the relatively flat tops of the dissected high fan remnants on the TRB of Po Chhu in the Nawakha – Jangwakha area. These gently sloping ares are almost entirely used for chhushing, and there is no need to define a non-chhushing equivalent of Nawakha series. These soils were described and sampled in 3 profiles in the survey area.

The topsoil is greyish brown sandy clay loam, with abundant orange and reddish brown chhushing-type mottles. The structure is subangular blocky typical of chhushing topsoils, but the consistence if slightly friable and not particularly cloddy. The subsoil is brown – reddish sand clay. There are common reddish brown mottle s throughout. Black manganese stains are concentrated in the upper subsoil, above 50-60 cm in some profiles but abundant and widespread in others. The subsoils have moderate subangular blocky structures and slightly friable- slightly firm consistence. There are few angular quartz stones. This soil is deep with no traces of weathered rock in the upper 1.5 m. Th

The analyses of these soils show >>>>>

5.7.7 Thara series

This series is for the Thimphu fan alluvium chhushing soils with greyish and brown loamy subsoils. They are most extensive of the Thimphu chhushing fan soils. They occupy most of the large fan of Nyakalumpa Chhu and, to a lesser extent of the fan of Shoshi Rong Chhu and some smaller fans off the main valley of Mo Chhu. They also occur on the lower fan of Shenga Rong Chhu, and in the Tsiphu and Dawakha areas of the Po Chhu valley. * profiles were described and sampled during this survey . Two of these are repeats of profiles that appeared in the Nyakalumpa report (see PT004 and PT013 in SSU Report 9a , 1999).

The topsoils are very dark grey-greyish brown sandy loams. In some profiles they extend deeper by merger with shallow buried topsoils. They have moderately developed subangular blocky structures, which have a tendency to break into crumb. The subsoils are dark greyish brown - yellowish brown to dark grey sandy clay loam with some horizons containing a few stones of soft and hard quartz and gneiss. The structure is moderate to weak medium subangular blocky, often breaking into fine crumb. As these soils are formed in deep fan alluvia there is no rock, weathered or fresh, within 2 m of the surface, and usually considerably deeper. The subsoils may include deeply buried topsoils, giving darker horizons.

The organic carbon is low and the total nitrogen is very low. C:N ratios are favourable. The topsoils of these profiles are very acid to neutral, and the pH value of the subsoil horizons are neutral to slightly alkaline. The available P is very low to low. The TEB is low with 3.0-5.7 me%. The exchangeable cations are variable with Ca^{++} dominant. The BS% is very high and the available K is higher in the top soil than the subsoil, even though they both are low.

5.7.8 Yuewakha series

This series is for the Thimphu chhushing soils on bouldery fans and have stony greyish and brown loamy subsoils. They are less extensive than the relatively non- stony soils of Thara series. They are extensive on the large fan of Shoshi Rong Chhu. They occur as patches on the fans of Nyakalumpa Chhu, lower Shenga Rong Chhu, and the smaller fans off the main valleys of Mo Chhu and Po Chhu. * profiles were described and sampled during this survey .

The topsoils are very dark grey-greyish brown sandy loams. In some profiles they extend deeper by merger with shallow buried topsoils. They have moderately developed subangular blocky structures, which have a tendency to break into crumb. The subsoils are dark greyish brown - yellowish brown to dark grey sandy loam – sandy clay, with many or abundant subangular stones or boulders. The structure and consistence of the subsoils are dominated by the high contents of stones but the interstitial fine earth is moderate to weak medium subangular blocky.

The organic carbon is low and the total nitrogen is very low. C:N ratios are favourable. The topsoils of these profiles are very acid to neutral, and the pH value of the subsoil horizons are neutral to slightly alkaline. The available P is very low to low. The TEB is low with 3.0-5.7 me%. The exchangeable cations are variable with Ca^{++} dominant. The BS% is very high and the available K is higher in the top soil than the subsoil, even though they both are low.

5.7.9 Hebesa series

This series is for the Thimphu fan alluvium chhushing soils with imperfectly drained subsoils. They occur as patches on all of the the fans of Nyakalumpa Chhu, lower Shenga Rong Chhu, and the smaller fans off the main valleys of Mo Chhu and Po Chhu. * profiles were described and sampled during this survey

The topsoils are very dark grey-greyish brown sandy loams. In some profiles they extend deeper by merger with shallow buried topsoils. They have moderately developed subangular blocky structures, which have a tendency to break into crumb. The upper subsoils are dark greyish brown - yellowish brown to dark grey sandy clay loam with some horizons containing a few stones of soft and hard quartz and gneiss. The structure is moderate to weak medium subangular blocky, often breaking into fine crumb. The lower subsoil is slightly wet - wet and has grey matrix colours, often with dark reddish brown rust mottles along root channels. The imperfect drainage and gley colours tends to mask any buried topsoils that may be present.

The organic carbon is low and the total nitrogen is very low. C:N ratios are favourable. The topsoils of these profiles are very acid to neutral, and the pH value of the subsoil horizons are neutral to slightly alkaline. The available P is very low to low. The TEB is low with 3.0-5.7 me%. The exchangeable cations are variable with Ca^{++} dominant. The BS% is very high and the available K is higher in the top soil than the subsoil, even though they both are low.

5.7.10 Lungkha series

This series is for the Thimphu fan alluvium chhushing soils with well drained, fairly stone-free but very sandy subsoils. They were mainly seen as patches on all of the fan of lower Shenga Rong Chhu, and the smaller fans off the main valleys of Mo Chhu and Po Chhu. * profiles were described and sampled during this survey.

The topsoils look quite similar to those of Thara series . They are very dark grey-greyish brown sandy loams. In some profiles they extend deeper by merger with shallow buried topsoils. They have moderately developed subangular blocky structures, which have a tendency to break into crumb. The subsoils range in colour from greyish brown - yellowish brown to grey. The textures are more or less layered according to depositional processes but sand and loamy sand predominate. There are few stones of soft and hard quartz and gneiss. The structure is weak medium subangular blocky, often crumbling to single grain.

The organic carbon is low and the total nitrogen is very low. C:N ratios are favourable. The topsoils of these profiles are very acid to neutral, and the pH value of the subsoil horizons are neutral to slightly alkaline. The available P is very low to low. The TEB is low with 3.0-5.7 me%. The exchangeable cations are variable with Ca^{++} dominant. The BS% is very high and the available K is higher in the top soil than the subsoil, even though they both are low.

5.7.11 Kubji series

This series is for the Thimphu alluvial fan chhushing soils with reddish brown or red lower subsoils. They are formed on fans where there is a substantial skarn/amphibolite component in the alluvium. They occur on the southern side of the Nyakalumpa fan and are extensive on the lower fan of Shanga Rong Chhu. * profiles have been described and sample in these soils including three repeats from the Nyakalumpa Chhu re[oat (see profiles PT005, PT011 and PT012 in SSU Re[ort 91, 1999).
These soils are alluvial, and more than 100 cm deep.

The upper horizons have been greatly modified by chhushing and are morphologically similar to those of Thara series. The topsoils are greyish brown to grey sandy loams. They have moderate medium subangular blocky breaking to moderate fine subangular blocky structures. This grades to greyish brown sandy loam – sandy clay upper subsoils, often with black FeMn stains and a few soft concretions. The lower subsoil is dark reddish brown to dark red sandy clay loam to sandy clay. It contains stones of various size and shapes, consisting of quartz and gneiss. The structures in the subsoils vary from moderate angular blocky to subangular blocky, breaking to moderate medium subangular blocky to weak fine crumb.

These profiles have low to moderate organic carbon and very low total nitrogen. The available P in these profiles range from 1-8 me% which is very low to low. TEB vary from 2.2-3.7 me% in the topsoil and 4.2-7.5 me% in the subsoil. The BS% is moderate to high. The cation balance is variable but Ca^{++} is usually the dominant exchangeable cation. The cation exchange capacity is low.

5.7.12 Botaka series

5.8 Chhushing soil series on Chekha formation parent materials

5.8.1 General relationships and differences between chhushing Chekha series

Only small areas of hillside chhushing on Chekha formation were seen in this survey, in the upper part of the Shengana (Shenga Rong Chhu) valley. The only previous area of chhushing hill soils developed in Chekha parent materials seen by SSU is at Radhi in Eastern Bhutan (SSU Report SS5a, 2000). However these are developed in colluvium from the Lower Chheka, which appears to have a higher proportion of phyllite and less granite and limestone than the

Middle Chekha, which are the source rocks for Shengana. Three classes were defined for Radhi, but only two of these are thought to be extensive in the survey area. They are developed in medium grained colluvium, largely derived from granite and quartzite, and have reddish subsoil colours. They are differentiated on depth between Panthang (shallow) and Tsangkahr (deep) series. A new series, Jarigang, is defined for the brown- grey equivalent of Tsangkhar series. This is coarser textured than the grey-brown loams and clays of Radhi series. No shallow equivalents of Jarigang series were seen. Rdahi series iicluded in Tables 5.1 1nd 5.3 but it is thought to be rare in the survey area.

The mostly extensive chhushing soils in upper Shengana are on Chekha-derived fan alluvium. Two series, the more extensive well drained Shengana series and the subordinate imperfectly drained Gangta series, are defined.

The series are summarised in Table 5.3

5.8.2 Jarigang series

The soils of this series are Chekha-derived residual and colluvial grey sandy loams. They are moderately extensive in the Jarigang area in upper Shengana. They are more exetnsive than their finer textured and shallower equiavalrnts in Radhi series. * Jarigang profiles were described and sampled in this survey.

The topsoil is dark grey fine sandy loam with district reddish brown mottles. It has a coarse subangular blocky structure, which dries to hard clods. However the moist consistence is moderately friable. The subsoil is dark greyish or yellowish brown heavy sandy loam or sandy clay loam, with reddish brown mottles and scattered multi-coloured patches derived from fragments of weathered granite and phyllite. It has a moderate – strong subangular blocky structure with strong but discontinuous clayskins. The lower subsoil material is a colluvial mixture of soil and weathered pieces of phyllite and quartzite, but bedrock is usually below 100 cm.

These soils have neutral topsoils, possibly due to prolonged use for irrigated rice. The subsoils are acid, with pH (water) in the range 5 – 5.5. In Profile Pd023 the base status does not accord with the pH values as the base saturation is lowest (<40%) in the neutral topsoil, and rises to >50% in the acid subsoil samples. Organic carbon, total nitrogen and available P are all low - very low. As in the grey clays, the contents of exchangeable and available K are both suprisingly low.

5.8.3 Radhi series

These are the fine textured equivalent of Jarigang series. They also tend to be shallower. They are thought to be unimportant in the survey area and it is not even certain that they occur. There are no described and sampled profiles in these soils in the survey area but a profile there is one in the Radhi reports (see PC007 in SSU Report 6a, 2000).

The main morphological features are thought to the dark colours and the medium-fine textures. The topsoils are mostly greyish brown with reddish brown mottles. Some of them may be quite light coloured (light brownish grey) due to prolonged use for irrigated rice. The textural range for the series is from fine sandy loam to silty clay. Topsoil structures are medium subangular blocky when moist but these soils dry to hard clods. The subsoils are mainly dark grey or dark greyish brown with faint brown mottling. Subsoil consistence is mostly slightly firm when moist. There are variable contents of phyllite and quartzite stones, depending on mixing. The weathered rock, at depths mostly less than 100 cm, and has a higher proportion of phyllite than that under the Jarigang series.

The topsoils are acid, with pH in water about 5.5. The pH increases to become only slightly acid or neutral at depth. The exchangeable base status also increases with depth, with base saturation rising from about 50% in the topsoils to about 65-80% in the subsoils. Organic matter levels are low, probably due to the prolonged cultivation for irrigated rice. The artificial nature of some of these soils shows up in the organic carbon profiles, with rises in the subsoils attributed to former topsoils that have been buried during terrace construction. Total N is also low but C:N ratios are mostly satisfactory, in the range 10-15. Available P contents are high in Profile PC007, probably due to recent FYM applications. The contents of exchangeable and available K are both suprisingly low in view of the abundance of K-bearing micaceous minerals

5.8.4 Panthang series

The soils of this series are not extensive in the survey area. * profiles were described and sampled during this survey. There are also 2 profiles in somewhat similar soils in the Radhi report (see PC009 and PC010 in SSU Report 6a, 2000).

The topsoil is dark greyish brown very fine sandy loam with a medium subangular blocky structure. The subsoil is brown sandy clay loam but grades to reddish brown at depth. It has yellow, black and orange but no grey mottles and appears to be well drained. Subsoil structures are coarse subangular blocky with weak discontinuous clayskins. By definition this series is less than about 100 cm to weathered rock.

These soils are neutral or slightly acid. In one profile the pH is highest at the surface and decreases in the subsoil, but the trend is reversed in the other two. However the differences are not very marked in any of them. Base saturations are high (>50%) throughout, except in the one topsoil in which the pH has been raised by rice cultivation. The high base status is mostly due to moderate contents of exchangeable Ca. Organic carbon, total N and available P are very low in all profiles. The contents of exchangeable K are low - moderate but available K is low.

5.8.5 Tsangkhar series

This series is the deep equivalent to Panthang series. These are not extensive in the survey area. * profiles were described and sampled during this survey. There are also 5 profiles in similar soils in the Radhi report (see PC008, PC010, PC026, PC027,and Pd022 in SSU Report 6a, 2000).

The topsoil is dark greyish brown very fine sandy loam with a medium subangular blocky structure. The subsoil is brown sandy clay loam but grades to reddish brown at depth. It has yellow, black and orange but no grey mottles and appears to be well drained. Subsoil structures are coarse subangular blocky with weak or moderate discontinuous clayskins. By definition this series is more than about 100 cm to weathered rock.

These soils are neutral or slightly acid. In one profile the pH is highest at the surface and decreases in the subsoil, but the trend is reversed in the other two. However the *differences are not very marked in any of them. Base saturations are high (>50%) throughout, except in the one topsoil in which the pH has been raised by rice cultivation. The high base status is mostly due to moderate contents of exchangeable Ca. Organic carbon, total N and available P are very low in all profiles. The contents of exchangeable K are low - moderate but available K is low.*

5.8.6 Shengana series

This is the main series defined for the Chekha fan alluvium chhushing soils. These soils occur on the upper fan of Shenga Rong Chhu, around Shengana village. * profiles were described and sampled during this survey (see Table 5.2). This is a new series to SSU and does not appear in previous reports.

Morphologically they are similar to the soils of Thara series. These series mat be merged in the future. However we shall retain the distinction based on source rock for the present.

These soils are well drained. The topsoils are very dark grey-greyish brown sandy loams with moderate subangular blocky structures, which have a tendency to break into crumb. The subsoils are dark greyish brown - yellowish brown to dark grey sandy clay loam, with few mottles in the deeper subsoil horizons. There are a few soft and hard stones. The structure is moderate to weak medium subangular blocky, breaking to fine crumb. The subsoils may include deeply buried topsoils, giving darker horizons. These soils are formed in deep fan alluvia and there is no rock in the top 2 m.

5.8.7 Gangka series

This series is the imperfectly drained equivalent of Shengana series. It occurs as limited areas in small patches in chhushing on Chekha fan alluvium. Like Shengana series, these soils occur on the upper fan of Shenga Rong Chhu, around Shengana village. * profiles were described and sampled during this survey (see Table 5.2). This is a new series to SSU and does not appear in previous reports.

Morphologically the upper parts of the profile resemble Shengana series. They differ in that the lower subsoil (below 50 cm) is somewhat wet, and has grey matrix colours and distinct rust mottling.

The topsoils are very dark grey-greyish brown sandy loams with moderate subangular blocky - crumb structures. The upper subsoils are dark greyish brown - yellowish brown to dark grey sandy clay loam. The deeper subsoil horizons. There are a few soft and hard stones. The structure is moderate to weak medium subangular blocky, breaking to fine crumb. The subsoils may include deeply buried topsoils, giving darker horizons. These soils are formed in deep fan alluvia and there is no rock in the top 2 m.

5.9 Chhushing soil series on main river alluvia

5.9.1 General relationships and differences between chhushing series on main river alluvia

As in the non-chhushing soils, no attempt is made to separate the chhushing soils in long distance alluvia of the main rivers according to specific geological formations. The soils are grouped according to the height of the alluvial parent material above the current level of the rivers, as summarised in Table 5.4.

There are fewer series compared to the non-chhushing soils because the floodplain and the steep bouldery terrace risers are not practicable for chhushing development. As expected from the non-chhushing soils, the general pattern of increasing thickness of the overlying silty and loamy with increasing height above river and deposit age is also found in the chhushing soils.

5.9.2 Bajothangka series

This is the chhushing equivalent of Dochhuka series. These soils occupy low river terraces along the main rivers, at heights of 3 – 10 m above current river levels.

* profiles were described and sampled in this survey (see Table 5.2), * of which are repeats from from the Nyakalumpa report (PT0** in Report SS9a, 1999). There is also a profile for this series in the Lingmutey Chhu survey (PH020 in SSU Report SS5a, 1999) and four profiles at Bajo RNR-RC (PK022, PK024, PK027 and PK031 in SSU Report SS3a, 1998). Profile DT-7 in Drukpa (1996) also qualifies for this series.

A few of soils in this series have thin surface skins of red silty clay. It is caused by the deposition of suspended material from irrigation water. The sediment is derived from the erosion of the red loams and clays of the skarn/amphibolite hills. The skin is a temporary feature and the reddish colour disappears when cultivation or cattle poaching disturb the surface.

The normal profile for this series has two or three distinct sections. The upper part of the profile has a hard (when dry) grey or greyish brown topsoil of silty clay, silty loam, fine sandy clay or fine sandy loam. This grades into a hard, pale brown – light grey upper subsoil of similar textural range. The depth of this upper section varies between 30 and 100 cm. In some soils it abruptly overlies a densely packed bed of highly rounded granitic or quartzitic river boulders. In other soils the silty upper section and the boulder bed are separated by a layer of more or less stone-free sand or loamy sand. This is very pale coloured, often white, loose, and fine or medium grained. There may be thin lenses of silt or fine gravel in the sandy layer.

Soils of this series have very acid topsoils but this grades through slightly acid and is slightly alkaline by 50 cm depth, and continues thus to depth. Topsoil organic carbon content and total nitrogen levels are low, and become very low at depth. This is probably an effect of the prolonged cultivation for wetland rice. Cation exchange capacities are moderate in the silty and loamy horizons, but are very low in the underlying sands. The soil is fully base saturated except for the acid topsoil. Available P levels are low throughout. These chemical characteristics are confirmed by the analyses of the lower terrace soils at Bajo RNR-RC, except that none of them had pH values below 6.5, and some topsoils there had high available P levels, presumably due to recent fertilizer applications.

5.9.3. Wangjokha series

The soils of this series occupy the river terraces at elevations of 10 – 25 m above the current river level. They are the chhushing equivalent of Laku series. They are extensive and are among the more important chhushing soils in the survey area.

> * profiles in these soils were described and sampled in this survey (see Table 5.2). There are also two profiles of this series in the Lingmutey Chhu report (PH017 and PH027 in SSU

Report 5a , 1999). There are Four described and analysed profiles in soils of this series in the Bajo RNR-RC report (PK023, PK026, PK028 and PK029 in SSUP Report SS3a, 1998). Profile DT-6 in Drukpa (1996) also qualifies for this series.

As in Bajothangka series, a few soils in this series have thin reddish veneers of bright red loam and clay, deposited from irrigation water. This is a temporary feature that is soon lost. The normal topsoil is light grey – pale brown in colour, and shows little organic darkening. Textures vary from sandy loam to silty clay. The topsoil is structured as coarse blocks – cultivation clods, and the dry consistence is hard. The subsoil consists of layers of grey and pale brown mottled layers of variable texture, ranging from sandy loam to silty clay. Structures are predominantly medium and coarse subangular blocky. The subsoils are hard when dry but the moist consistence varies from friable to very firm. Consistence tends to be firmer with high silt contents. There are a few rounded pebbles and cobbles (diameters up to 10 cm) in these soils but they are not concentrated as beds. The alternation of loam and fine loamy horizons continues to of 1.5+ m, and no lenses of loose sand or beds of boulders were seen. However, road cuttings show beds of sand and boulders in these deposits, at depths below 2 m.

The two profiles in these soils have similar chemical characteristics. Both are slightly acid-neutral in the topsoil but slightly alkaline in all horizons below. Organic carbon and total nitrogen levels are low in the topsoils and very low in the subsoil horizons. Cation exchange capacities are low - very low, as there is little contribution from organic matter and clay contents are low - moderate. However, the CEC's are fully saturated, as is expected from the pH. These characteristics are confirmed by the analyses of the similar soils at Bajo RNR-RC.

5.9.4 Matalungchhu series

The soils of this series occur on terraces at 30 – 45+ m above the current river levels. They are the chhushing equivalent of Mendegang series. There is a large area of these soil around Mendegang in the lower valley of Shenga Rong Chhu, but they are not extensive elsewhere in the survey area.

There are * described and sampled profiles for this series from this survey. Additional profiles of this series can seen in the Lingmutey Chhu report (profile PH026 in SSU Report 5a, 1999).and profile DT-8 in Drukpa (1996).

The profile morphology of the soils of this series is somewhat similar to that of Wangjokha series. The topsoil is pale coloured and of hard consistence when dry. The surface structure is usually blocky-cloddy, but platy surface layers also occur. The subsoils are greyish – brown to light grey. A feature of these soils is the intensely developed red, brown and black ferri-manganese mottling in the subsoils. In places the black mottling is sufficiently concentrated to constitute on incipient manganese pan. Similar mottling occurs in Wangjokha and Bajothangka series, but is not as marked or as concentrated. Increasing segregation of manganese with increasing height and age of alluvial deposits has been noted in the river terraces in the valley of Chamkar Chhu at Bumthang (SSU Report 2a**,** 1998). Textures vary according to alluvial deposition, ranging from sandy loam to silty clay in the upper metre, with high contents of silt and fine sand. Loose loamy fine and medium sand may occur in the lower subsoil. There are occasional rounded pebbles throughout the profile, but there are no stone layers or boulder beds in the top 2 m.

The chemical characteristics of this series are similar to those of Wangjokha and Bajothangka series*. The topsoil is slightly acid but the lower horizons are neutral or slightly alkaline. Base saturations are high throughout. Organic carbon is low – very low. Total nitrogen is very low in the topsoil, and none was detected in any subsoil horizon in Profile PH026.*

Available P varies erratically with depth, from very low to high, with the maximum value recorded in a very sandy horizon at below 1m.

5.9.5 Jibjokha series

This series was seen in only one location in the survey area, on the 80 m terrace just below and to the east of Jibjokha school. The topography is a gently sloping bowl, merging gradually upslope with a wide low angle fan. As discussed above, this deposit may be an old floodplain backswamp or it may be truly lacustrine. The alluvial deposit appears to have been overlain by local hillwash material in places. The series has been described in detailed and sampled for analysis in two profiles.

The topsoil has many chhushing features, such as grey matrix colours, many reddish brown and orange mottles, blocky structures and hard consistence when dry. Textures vary from sandy loam to sandy clay loam, with mainly firm and medium grained sands. The upper subsoil is grey – greyish brown with common mottles, and textures are similar to the topsoil. The alluvial origins of these soils show below 1m, where there are beds of single grained river sand of medium and fine grain,. In of the two profiles there is a layer of mucky-humic loam, which smells sulphidic.

The analytical data from the two profiles ……

5.10 Series summaries

Table 5.5 summarises the main site and morphological features of the series, and Table 5.6 summarises the analytical data for the samples collected within the survey area.

Table 5.4 Soil series derived from main river alluvial parent materials in Punakha

Non-Chhushing		***Chhushing***	
Differentiating features	***Series***	**Differentiating features**	***Series***
Floodplain, < 3 m above river, boulders < 1m deep	*Jhimsa*		
Low terrace, < 10 m above river, boulders < 2 m deep	*Dochukha*	Low terrace, 3 - 10 m above river, sandy subsoil , boulders < 2 m deep	*Bajothangkha*
Medium terrace, 15 - 25 m above river, boulders > 2 m deep	*Laku*	Medium terrace, 15 - 30 m above river, boulders > 1 m, often > 2 m deep	*Wangjokha*
High terrace, > 30 m above river, boulders > 2 m deep	**Mendhegang**	High terrace, 35- 45 m above river, boulders > 2 m deep	*Matalungchhu*
Outcropping bouldery soils on steep terrace risers	**Churidho**	High terrace, ca 80m above river, no boulders seen, sulphidic peat/muck at > 1 m	*Jibjokha*

Table 5.5 Summary of main site and morphological characteristics of soil series of Punakha arable lands

Series	*Landuse*[1]	*Parent material*		*Landform*	*Drainage*	*Main subsoil:*		*Depth to weathered rock (cm)*	*Profiles*	
		Source rock	*Drift*			*- Texture*	*- Colour*			
Thimphulem	N	Any Thimphu	Colluvium + residual	Hill slope declivities	Poor	Medium & heavy	Grey	Any		
Yusipang		Thimphu GQG[2]		Hill slopes	Good		Bright brown or reddish yellow	<100		
Bathpalathang								>100		
Khangma							Dark or greyish brown (buried topsoil)	<100		
Kanglung								>100		
Norbugang		Thimphu SAB[3]				Heavy	Red	<100		
Laptsakha								>100		
Gyonchhukha						Medium		<100		
Walakha								>100		
Talo						Medium & heavy	Dark brown	>100		
Ololem		Any Thimphu	Fan alluvium	Side valley fan	Poor	Medium & heavy	Grey (some mottles)	>100[4]		
Hongtsho					Imperfect		Greyish + many mottles			
Semtokha					Good		Bright brown or reddish yellow			
Khuru				Terrace in side valley fan						

Series	***Landuse[1]***	**Parent material**		***Landform***	***Drainage***	***Main subsoil:***		***Depth to weathered rock (cm)***	***Profiles in this survey***	***Oth BB sur are***
		Source rock	***Drift***			***- Texture***	***- Colour***			
Chekalem	Non Chhushing	Any Chekha	Colluvium & Residual	Declivities in hillslopes	Poor	Medium	Grey	Any		
Khardung		Chekha Q, G, & P[5]		Hillslopes	Good	Medium	Bright brown or reddish yellow	>100		
Chaling		Chekha P (+ G & Q)	Colluvium + residual	Hillslopes	Good	Heavy	Bright brown or reddish yellow	>100		
Thongbji		Any Chekha	Fan alluvium	Alluvial fan	Good	Medium & heavy	Brown & greyish brown	>100		
Chayukha		Mixed	Main river alluvium	Floodplain, < 3m						
Dochukha				Main river terrace, < 10m						
Laku				Main river terrace, 15 –25 m						
Chhuridho				Main river terrace, > 35m						
Doda		*Any Chekha*	*Colluvium + residual*	*Hillslope*	*Good*	*Coarse + moderate*	*Strong brown / reddish brown*	*< 100*		
Mendegang		*Mixed*	*Alluvial deposit*	*Main river terrace (35-45m)*	*Good*	*Fine + slightly heavy*	*Light greyish brown*	*> 100*		
Dompola	*Chhushing*	*Thimphu*	*Colluvium + residual*	*Hillslope*	*Good*	*Medium moderate*	*Grey t0 strong brown*	*< 100*		

Kyelikha		*Thimphu*	*Colluvium + residual*	*Hillslope + declivities of hillslope*	*Good*	*Fine Light - moderate*	*Greyish brown*	*> 100*		
Gumakha		*Thimphu*	*Colluvium + residual*	*Hillslope*	*Good*	*Fine light - moderate*	*grey*	*< 100*		
Umtekha		*Thimphu Skarn + amphibolite*	*Colluvium + residual*	*Hillslopes*	*Good*	*Medium moderate – heavy*	*Red – reddish brown*	*> 100*		
Nawakha		*Thimphu*	*Fan alluvium*	*Dissected high fan*	*Good*	*Fine Slightly heavy*	*Brown – reddish brown*	*> 100*		
Thara		*Thimphu*	*Fan alluvium*	*Alluvial fan*	*Good*	*Medium moderate*	*Greyish brown – dark grey*	*> 100*		
Yuewakha		*Thimphu*	*Fan alluvium*	*Bouldery alluvial fan*	*Good*	*Medium Slightly heavy*	*Dark greyish brown – yellowish brown*	*> 100*		
Hebesa		*Thimphu*	*Fan alluvium*	*Fan alluvial*	*Imperfect*	*Medium heavy*	*Grey/ Gley colours*	*> 100*		
Lungkha		*Thimphu*	*Fan alluvium*	*Alluvial fan*	*Good*	*Very coarse Very light (sandy)*	*Greyish brown - grey*	*> 100*		
Kubji		*thimphu*	*Fan alluvium*	*Alluvial fan*	*Good*	*Fine heavy*	*Dark reddish brown – dark red*	*> 100*		
Botokha										
Jarigang		*Chekha*	*Colluvial*	*Hillslope*	*Good*	*Fine-medium moderate*	*Dark grey – yellowish brown*	*> 100*		
Radhi		*Chekha*	*Colluvium + residual*	*Hillslope*	*Good*	*Fine-medium moderate*	*Dark grey – greyish brown*	*< 100*		

Pangthang		*Chekha*	*Colluvium + residual*	*Hillslope*	*Good*	*Fine moderate*	*Brown – reddish brown*	*< 100*		
Tshangkhar		*Chekha*	*Colluvium + residual*	*Hillslope*	*Good*	*Fine moderate*	*Brown – reddish brown*	*> 100*		
Shengana		*Chekha*	*Fan alluvium*	*Alluvial fan*	*Good*	*Fine-medium moderate*	*Dark greyish brown-yellowish brown*	*> 100*		
Gangkha		*Chekha*	*Fan alluvium*	*Alluvial fan*	*Good*	*Fine-medium moderate*	*Dark greyish brown-yellowish brown*	*> 100*		
Bajothangkha		*Mix*	*Alluvial deposit*	*Main river terrace (3-10m)*	*Good*	*Fine-coarse Very light (sandy)*	*Pale brown-light grey*	*> 100*		
Wangjokha		*Mix*	*Alluvial deposit*	*Main river terrace (10-25m)*	*Good*	*Medium – slightly heavy*	*Grey-pale brown*	*> 100*		
Matalungchhu		*Mix*	*Alluvial deposit*	*Main river terrace (30-45m)*	*Good*	*Medium – slightly heavy*	*Greyish brown – light grey*	*> 100*		
Jibjokha		*Mix*	*Alluvial deposit*	*Main river terrace (80m)*	*Good*	*Medium moderate*		*> 100*		

1 *C = Chhushing,* *N = Non-chhushing*

2

Table 5.6

Table 5.6 Summary of analytical data ranges for Punakha arable soil series

		Series						
Depth		**Thimphulem**	**Yusipang**	**Bathpalathang**	**Kangma**	**Kanglung**	**Nobgang**	**Laptsakha**
0-10 cm	n							
	pH(w)							
	Org C %							
	Tot N %							
	C:N							
	Av P ppm							
	Av K ppm							
	X Ca me%							
	X Mg me%							
	X K me%							
	X Na me%							
	TEB me%							
	CEC me%							
	BS %							
	X Al me%							
	X H me%							
	ECEC me%							
	EBS %							

Main subsoil horizon	n							
	pH(w)							
	Av P ppm							
	Av K ppm							
	X Ca me%							
	X Mg me%							
	X K me%							
	X Na me%							
	TEB me%							
	CEC me%							
	BS %							
	X Al me%							
	X H me%							
	ECEC me%							
	EBS %							

6 SOIL CORRELATION

6.1. Correlation with soils mapped Bhutan

As SSU have done 13 soil surveys in Bhutan, it is possible to indicate which of the Punakha soils are similar to those seen elsewhere in the country.

Table 6.1 summarises the occurrence of the Punakha soils series in other SSU survey areas, and the local soil class names given in the reports written before a series system had been drafted. Soil classes in other surveys that do not occur in Puna Tsang Chhu area are not in Table 6.1.

The assumptions in Table 6.1 include:

1. The distinction between chhushing and non-chhushing soils was not made in earlier surveys. Many of the earlier soil classes can be assigned to the new series, but some cover both chhushing and non-chhushing soils

2. The series on the different levels of river terraces along Puna Tsang Chhu are the same throughout the Wangdi-Punakha Inner Valley, from Dawakah in the north to Bajo in the south.

3. The series on the river terraces of Puna Tsang Chhu are different from those on the terraces of the other main Inner Valleys of Bhutan, such as the terrace soils along Chamkar Chhu at Bathpalathang.

4. The shallow and deep non-chhushing hill soils derived from the Thimphu gneiss (Yusipang and Bathpalathang series) are assumed to be the same over an altitude range from 1300 m in Puna Tsang Chhu to over 2700 m at Bathpalathang.

5. The red clays and loams derived from skarn/amphibolite were not subdivided in the Lingmutey Chhu survey, and probably include some of all of Gyenchhuka, Laptsakha, Norbugang and Walakha series. However it is not thought that Talo series occurs at Lingmutey Chhu.

6. The footslope soils at Yusipang have been taken as colluvial, and correlated with Yusipang and Bathpalathang series.

7. The present series do not make separate provision for imperfectly drained non-chhushing hill soils. As there are series for imperfectly drained fan soils, this is an anomaly. For the present the imperfectly drained footslope hill soils at Yusipang are correlated with poorly drained soils of Thimphulem series.

8. The 80 m terrace soil of Jibjokha series, which has a mucky/peaty horizon in the subsoil, may be similar to the old lacustrine soil above Limbukha village in the Lingmutey Chhu survey.

9. The correlations between the grey and brown Chheka-derived soils in upper Shengana and those at Radhi are problematic. The Radhi soils are derived from the Lower Chheka, which appears to have more phyllite and less granite than the Lower-Middle Chheka that are the main source rocks for Shengana. The areas are also quite different topographically. Radhi is a complex of jumbled lower slope colluvium and multiple landslips, whereas Shengana has distinct simple lower slopes and a large multi-phase fan. Radhi series in included in Table 6.1 but may be rare in Shengana, as most of the Shengana hill chhushing soils are coarse or medium textured and Jaringanag series predominates.

10. The correlations of the reddish brown clays with the much brighter red clays and loams in Punakha are also tentative.

Table 6.1 Correlation of Punakha soil series with previous SSU surveys

	Soil classes in previous SSU surveys & reports							
	Yusipang SSUP 1a	**Bathpalathang SSUP 2a**	**Bajo SSUP SS3a**	**Khangma SSUP SS4a**	**Lingmutey Chhu SSUP SS5a**	**Radhi SSU 6a**	**Nyakalumpa SSUP SS10a**	**RBG Serbithang SSU SS12a**
Soil series								
Bajothangkha			Tl		TL		TL	
Bathpalathang	Hd, Ff	Hd		DB, DF	GD		HD, HM	HD
Botola								
Chaling						RBL		
Chhekalem						RHG		
Chhuridho		Rx	THr					
Datong					QO	RBS		
Dochukha								
Domphola					(SB, SF)			
Gangkha								
Gumakha								
Gyonchhuka					RC		HR	
Hebesa								

Hongthso	Vi							
Jaringay						RGL		
Jibjokha					(LB)			
Jimsa					RS			
Khanglung				SB, SF				
Khangma				DB, DF				
Khardung						RBS		
Khuru	LT						FT	
Kubji							FR	
Kyelikha				(DB, DF)			HD	
Laku								
Laptsakha					RC	RBC	HR	
Lungkha								
Matulungchhu					TU			
Mendegang								
Norbugang					RC	RBC	HR	
Ololem	Vg							

Panthang						RBL		
Radhi						RGC, RGL		
Yuewakha								
Semtokha	Vf							
Shengana								
Talo								
Thara							FB	
Tsangkhar						RBL		
Thongbji								
Thimphulem	Hg, Fg, Fi	Hg, Hi		HG				HG
Tsangkhar								
Umtekha					BR			
Walakha					RC		HR	
Wangjokha			Tm		TM		TM	
Yuewakha								
Yusipang	Hs, Hm	Hs		VS, SB, SF	GS, QG		HS	HVS, HMS
	Yusipang SSUP 1a	**Bathpalathang SSUP 2a**	**Bajo SSUP SS3a**	**Khangma SSUP SS4a**	**Lingmutey Chhu SSUP SS5a**		**Nyakalumpa SSUP SS10a**	**RBG Serbithang SSU SS12a**

6.2 Correlation with international soil classifications

The Bhutan series classification is intended indicate the main soil features to those interested specifically in the soils of Bhutan. The series will convey much to people outside Bhutan. The series are therefore correlated with the two main international systems of soil classification in Table 6.2. The versions of the international systems used are 1the 1998 version of WRB and the second edition of USDA Soil Taxonomy.

Table 6.2 International correlation of soil series of Puna Tsang Chhu

Soil series	**Subunit in FAO Soil Map of the World Legend of (FAO1974 & 1988)**	**Great group in USDA Soil Taxonomy (Soil Survey Staff 1975 & 1992) [Family in italics]**
Bajothangkha	Eutric Fluvisol	Anthraquic Ustifluvent [thermic, loamy skeletal, mixed]
Bathpalathang	Dystric & eutric Regosol, Dystric & eutric Cambisol	Typic Dystrustept & Haplustept, Typic Dystrudept & Eutrudept [thermic, loamy, mixed].
Botkaa	Hydragric Anthrosol	Anthraquic Haplustept [thermic, loamy & loamy skeletal, mixed]
Chaling	Dystric & eutric Cambisol	Typic Dystrustept & Haplustept, Typic Dystrudept & Eutrudept [mesic, loamy & loamy skeletal, mixed].
Chhekalem	Mollic, Umbric & * Gleysol	Typic & Mollic Epiaquept [thermic & mesic, loamy, mixed]
Chhuridho	Eutric & Dystric Regosol	Typic Ustorthent & Ustifluvent [thermic, skeletal, mixed]
Datong	Haplic Acrisol; Ferralic Arenosol	Arenic & typic Haplustult & Hapludult; Typic Ustipsamment & Udipsamment [mesic, sandy & coarse loamy, mixed]
Dochukha	Eutric Fluvisol	Typic Ustifluvent [thermic, loamy skeletal, mixed]
Domphola	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, loamy & loamy skeletal, mixed]
Gangkha	Hydragric & Gleyic Anthrosol	Anthraquic & Oxyaquic Haplustept, Dystrudept & Eutrudept [thermic, loamy, mixed]

Gumakha	Hydragric & Gleyic Anthrosol	Anthraquic & Oxyaquic Haplustept, Dystrudept & Eutrudept [thermic, loamy, mixed]
Gyonchhuka	Ferralic & chromic Cambisol;	Dystric & typic Haplustept; [thermic, loamy, mixed].
Hebesa	Hydragric & Gleyic Anthrosol	Anthraquic & Oxyaquic Haplustept, Dystrudept & Eutrudept [thermic, sandy & coarse loamy, mixed]
Hongthso	Eutric & Dystric Cambisol	Dystric & Typic Haplustept [thermic, loamy, mixed]
Jaringang	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, loamy, mixed]
Jibjokha	Eutric & Dystric Cambisol (Haplic Luvisol)	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, fine loamy, mixed]
Jimsa	Eutric Fluvisol, Eutric Regosol	Typic Ustipsamment [thermic, sandy, mixed]
Khuru	Eutric & Dystric Cambisol	Dystric & Typic Haplustept [thermic, loamy & loamy skeletal, mixed]
Khanglung	Ochric & Umbric Regosol	Typic Ustorthent [thermic, loamy, mixed]
Khangma	Ochric & Umbric Regosol	Typic Ustorthent [thermic & mesic, loamy skeletal, mixed]
Khardung	Haplic Acrisol	Arenic & typic Haplustult; [thermic, coarse loamy, mixed]
Kubji	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, fine loamy, mixed]
Kyelikha	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, loamy, mixed]
Laku	Eutric Cambisol (Eutric Fluvisol)	Typic Haplustept, (Typic Ustifluvent) [thermic, loamy, mixed]
Laptsakha	Haplic Luvisol & Lixisol, Rhodic Ferralsol	Typic Rhodustalf, Rhodustox or Rhodustult [mesic, clay, mixed].

Lungkha	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, sandy & coarse loamy, mixed]
Matulungchhu	Eutric Cambisol (Haplic Luvisol)	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, fine loamy, mixed]
Mendegang	Eutric Cambisol (Haplic Luvisol)	Dystric & typic Haplustept [thermic, fine loamy, mixed]
Norbugang	Ferralic & chromic Cambisol;	Dystric & typic Haplustept; [mesic, clay, mixed].
Ololem	Mollic, Umbric & * Gleysol	Typic & Mollic Epiaquept [thermic & mesic, loamy & loamy skeletal, mixed]
Panthang	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, loamy, mixed]
Radhi	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, fine loamy & clay, mixed]
Semtokha	Eutric & Dystric Cambisol	Dystric & Typic *Haplustept [thermic, loamy, mixed]
Shengana	Hydragric Anthrosol	Anthraquic, Dystrudept & Eutrudept [thermic, loamy, mixed]
Talo	Ochric & Umbric Regosol	Typic Ustorthent [thermic, loamy, mixed]
Thara	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, loamy, mixed]
Tsangkhar	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, loamy, mixed]
Thongbji	Mollic, Umbric & * Gleysol	Typic & Mollic Epiaquept [thermic, loamy, mixed]
Thimphulem	Mollic, Umbric & * Gleysol	Typic & Mollic Epiaquept [thermic mesic, loamy, mixed]
Tsangkhar	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, loamy, mixed]
Umtekha	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, loamy, mixed]

Walakha	Haplic Luvisol & Lixisol, Rhodic Ferralsol	Typic Rhodustalf, Rhodustox or Rhodustult [mesic, loamy, mixed].
Wangjokha	Eutric Cambisol (Eutric Fluvisol)	Anthraquic Haplustept, (Anthraquic Ustifluvent) [thermic, loamy, mixed]
Yuewakha	Hydragric Anthrosol	Anthraquic Haplustept, Dystrudept & Eutrudept [thermic, loamy skeletal, mixed]
Yusipang	Dystric & eutric Cambisol	Typic Dystrustept & Haplustept, Typic Dystrudept & Eutrudept [thermic, loamy & loamy skeletal, mixed].

The assumptions in Table 6.2 include:

1. As discussed in Chapter 2 it is assumed that the soils in the floor of the main N-S valleys have ustic moisture regimes, but those in the side valleys and on the hill slopes have udic SMR. This has the effect of assigning udic SMR to all of the Chheka-derived soils as they occur only in the side valley of Shengana. All of the main river alluvial soils are assumed to have ustic SMR. The Thimphu-derived hill and fan soils occur in areas with both ustic and udic SMR.

2. The soil temperature regimes are assumed to grade from thermic to mesic at an altitude of 1700 m a.s.l., so that the families in ST are all thermic. However this applies only for this survey and these soil series occur elsewhere with mesic STR, e.g. Lingmutey Chhu and Radhi (SSU Reports 5a & 6a, 2000).

3. Where series are separated on depth, it is assumed that the shallower series correlate mainly with Cambisols or Inceptisols. The deeper series also includes the less developed Cambisols/Inceptisols but some correlate with more developed Alfisols/Luvisols and Acrisols/Ultisols.

4. Where colluvial/residual non-chhushing series are defined in terms of buried topsoils, they are correlated with Regosols/Orthents. Their degree of weathering is probably little different from the bright coloured subsoil series, which are correlated with Cambisols/Inceptisols and with even more developed classes.

5. The soils on the terraces along the main N-S rivers main river are assumed to develop from Fluvisol/Fluvents, on the lower terraces and younger alluvia, to Cambisol/Inceptisols on the higher terraces and older deposits.

6. The deeper red soils (Laptsakha and Walakha series) vary in their chemical characteristics according the relative proportions of marble/amphibolite versus felsic rocks (gneiss etc.) in the local colluvium, and their correlations are variable. Similar considerations apply within the Inceptisols for the shallower red series, i.e. Norbugang and Gyenchhuka.

7. We have assigned all chhushing series to the Hydragric Anthrosols in WRB. There is no

'Anthraquic' subgroup of the Haplustepts in the 1999 version of ST, but we need it for correlation in the survey area. (SSU also needs similar subgroups in the Dystrudepts and Eutrudepts to accommodate chhushing soils in other parts of Bhutan).

8. The chhushing soils with imperfectly drained subsoils may qualify for Gleyic subunits in WRB and Oxyaquic subgroups in ST.

9. We need more data to know whether the present Datong series should be split between sandy and coarse loamy series. If done, this will separate the Acrisol/Ultisol and Arenosol/Psamment correlations.

10. The '-lem' series are mostly saturated by shallow lateral throughflow and are correlated with Epiaquepts, rather than groundwater-fed Endoaquepts, in ST. This distinction is not made in WRB.

7 SOIL DISTRIBUTION AND MAPPING

Table 7.1 Composition of soil mapping units for Puna Tsang Chhu

Mapping unit	Type	Main soil classes	Minor soil classes

The areas and proportions of the units for this map are summarised in Table 7.2.

Table 7.2 Areas of mapping units on soil map of Puna Tsang Chhu

Soil mapping unit	Area		
	ha	acres	% of survey area.
Yusipang	2133		
Laptsakha	1208		
Gyenchhuka	119		
Semtokha	19		
Domphola	337		
Kyelikha	128?		
Domphola/Kylekha	172		
Umtekha	320		
Nawakha	219		
Thara	148		
Kubji	239		
Lungkha			
Hebesa	22		
Botokha	47		
Yuewakha	130		

Dado	376		
Shengana	217		
Jasigang	252		
Jimsa	46		
Bajo	215		
Wangjokha	326		
Matalungchhu	25		
Jibjokha	23		
Rock complex	23		
Disturbed ground	92		
TOTAL	**6884**	**17000**	**100.0**

8 LAND EVALUATION

9 CONCLUSIONS

9.1 Soils of Punakha arable lands in national context

Lingmutey Chhu has been chosen for integrated watershed studies and activities for a complex of reasons, including social attitudes, physical access, and pre-existing work. It is of interest to know if the soils of the watershed are representative of large areas or are unique.

As SSUP is in its early stages, its field experience of Bhutan's soils is still limited. It is not therefore able to pronounce authoritatively on the typicality of Lingmutey Chhu's soils. However enough has been seen for it to be clear that soils similar to the brown sandy loam (GS and GD) are widespread on the extensive gneiss and schist parent materials in mid-altitude Bhutan. The grey stony sandy loams are also thought to be common in areas with abundant quartzite. It is not known if soils like the deep orange light sandy loams on the Shengana-Limukha quartzite ridge are common elsewhere. The terrace soils in the lower catchment are similar to others in the middle section of the Tsang Chhu valley.

There are extensive areas of soils like the red clays (RC) and the related brown-over-red soils in the Lobeysa-Walakha region, on the opposite (west) bank of Tsang Chhu. Similar soils extend far upslope from Walakha through Talo geog, and also up the valley of Tabe Rong Chhu towards Thinleygang. Small patches of similar soils are thought to be common throughout the very extensive Thimphu gneiss outcrop, and are largely determined by the occurrence of amphibolite dykes, carbonate beds or skarn bodies. They are particularly extensive and concentrated in this section of the middle Tsang Chhu valley. The dark brown clays (RM) may occur elsewhere on mafic, ultramafic and carbonate rock types under broadleaf forest, especially on slopes of northerly aspect.

Lingmutey Chhu therefore contains a variety of soils that are significant elsewhere, and the findings in the watershed will not be of restricted spatial relevance because of atypical soils. However other, non-soil, aspects may complicate extrapolation of Lingmutey Chhu results.

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N.B. This includes references in the report and also other background material on the physical environment of the area.

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APPENDIX A Profile Descriptions

APPENDIX B Summary of Punakha soil profiles

Series	*Puna Tsang temp. Number (series/ profile/ running total)*	***Profile No.***	***Landuse[1]***	***Parent material***		***Topo.***	***Drainage***	***Subsoil***					***Depth to weathered rock (cm)***
Name				***Source rock***	***Drift***			***- Texture***	***- Colour***	***- Mottles***	***- Stones***	***Buried topsoil?***	
Thimlem	1/1/1	Pd046	C	T gn	C	M sl/20/tx	imp	Fscl/mscl/ wr(cs)/fscl(wr)	Dgb/dg/g/ mx	M/c/c/mx	Z/z/c/f	N	31
Yusipang	2	Pd039	D	T gn + qtz	C	M sl /24/cx	g	Msl+/csl/ wr	Br/yb/wr	Z/z	F/f//wr	N	53
		Pd047	D	T gn + qtz	Shall c	M sl /30/r	g	Mscl/ wr(lcs)	Dgb/gb	C/c	Z/wr	N	59
		Pd051	D	T gn + qtz	Shall c	M sl /35/r	g	Fsl+/ msl*/wr wr(gvsl)	B/b/pb	M/c/ wr	Z/wr	N	77
	2/5/6	***PH043***	Chir regen	T gn	Shall c	M sl /16/tcv	g	Mscl/ msl+/csl/ wr(fsl)	yb/by/dyb /mx	Ab/m/c/mx	C/f/f//wr	Y	67
Bathpalathang	3												
Kangma	4												

Kanglun g	5	Pd038	D	T gn	C	Msl/30 /r	g	Msl/msl+/ fscl/	Dyb/b/b	Z/f/z/z	C/c/f/f	Y?	131+
	5/2/8	Pd060	C former	T gn	Coll	M sl/40/tr	imp	Csscl- /csscl- /msl+	Yb/db/g	Z/m/m	C/r/z	Y	150+
Norbuga ng	6												
Laptsakh a	7	PH080	Sf	T gn & skarn	C	Us/50/r	g	Zcl+/zc/z c	Yb/r/b	Z/z/m	F/f/z	N	86+
		PH081	F	T skarn	C	Ms/27/ r	g	Cl/c/zc	Yr/r/rb	Z/z/m	F/z/f	N	86+
	7/3/11	Pd068	C	T gn	Coll	M sl/20/tr	g	Msl/vfsc/ vfsc/vfsc	Dyb/b/yb/ yb	F/c/m/ab	R/r/z/f	N	270+
Gyochhu ka	8/1/12	Pd051	Fallow d	T gn	C	M sl/35/r	g	Fsl+/msl+ / wr(gvsl)	B/b/pb	M/c/wr	Z/r/wr	N	77
Walakha	9	PT010	Waste	T sk	C	M sl /28/gul l	g	Fscl/fsc/fs cl	drb	Z/z/	F/f/c	N	155+
		Pd029	Chir regen	T sk	C	l sl /i8/r	g	Fscl/fscl	Rb/drb	r/z	F/f/c	N	103+
		Pd036	D	T sk	C	m sl /8/r	g	Fscl/zic/zi cl (wr)	db/vdg/rb	z/m(wr)	F/wr	?y	130 +
	9/4/16	Pd044	Citrus	T sk	C	l sl /50/r	g	Fscl/	R/r/rb/drb	Z/z/z/zab d	z	N	205 +
Talo	10/1/17	Pd116	Wood land	T gn	Coll	M sl/26/tr	g	Fsl+/msl+ /msl+/msc l	Vdb/b/b/d b	Z/z/f/p	F/c/c/c	N	150+

Ololem	11												
Hongtsho	12												
Semtokha	13												
Khuru	14												
Dochhuka	15												
Laku	16												
Chhuridho	17												
Chekhalem	18												
Khardung	19/1/18	PH060	Bdlf	C gt &schist	C	Ls/65/r	g	Msl/msl/msl/msl/msl	Sb/sb/ey/sb	Z/z/c/c	C/m/c/c	N	110+
Datong	20/1/19	Pd077	Bdlf	Ch gnt?	Shall. c	L sl/35/r	g	Csl+/wr (gvs)/wr (msl+)/wr (gvS)	Yb/mx/by/mx	Z/mx/mx/mx	M/wr	N	38
Chaling	21												
Kyelikha	22	PH044	C	T gn & amp	C	L sl/45/tx	g	Ms+/msll/fscl	Gb/g/b/db	Ab/ab/c/m	Z/z/z	Y	120+

		PH050	C	T gn	C	L sl/20/cx	g	Fsl/csl/mx/msl	G/gb/mx/dg	M/c/ab	Ab/f/c/c	Y	96+
		PT001	C	T gn	C	L sl/20/tv	g	Lms/msl+/ms	Gb/dgb/pb	Ab/ab/z	Z/c/f	Y	90+
		PT002	C	T gn	C	L sl/10/tx	g	Fsl/msl/msl+ /mscl	Yb/vdgb/br	C/ab/f/ab/	Z/z/f	Y	120+
		PT003	C	T gn	C	L sl/35/tr	g	Fsl/msl/msl+	Gb/dgb/gb/yb	M/c/c/m	F/f/f/c	Y	102
		PT006	C	T gn	C	L sl/15/tv	g	Fscl/fsc	db/b/pb/b/rb	C/m/c	Z/f/f/z/f	N?	130+
		PT015	C	T gn	C	L sl/10/tr	g	Fsl/mscl/mscl/mscl+	Lbg/b/yb/g/db	M/c/	Z/f/z/z	Y x 2	155+
		PT022	C	T gn + qtz	C	Kn&col /5/tcv	g	Cscl/mscl/fscl	Lg/mx/dyb/mx	Ab/mx/m/mx	F/f/z/f	N	120+
		PT023	C	T gn + qtz	?Old alluv + coll	Kn&col /3/tcv	g	Csl/s/csl+	Dg/dgb/lolb/gb	Ab/ab/z/ab	F/f/z/f	N	120+
		PT024	C	T gn + qtz	?Old alluv + coll	Kn&col /5/tcv	g	Mscl/fswl/vfscl /hul	Dgb/mx/dg/vdg/bk	M/mx/z/z/z	F/f/fz/z	?peat	120+

		PT025	C	T gn + qtz	Old alluv + coll	Kn&col /5/tcv	g	Fsl+/msl/ mscl /ms	Dg/lolb/g b/lolb/ lbg	C/c/c/c	Z/f/z//z	N	157 st line
		Pd054	C	T gn	Coll	M sl/15/tr	g	Fscl/fscl/f scl	Ybr/ybr/l ybr	M/m/m	Z/z/z	N	135+
		Pd055	C	T gn	Coll	M sl/15/tr	g	Fscl-/fscl- /fsc/fsc	Ybr/gbr/d ybr/sb	Ab/ab/c/c	Z/r/z/z	N	132+
		Pd056	C	T gn	Coll	M sl/40/tr	g	Cssl+/cssl +/cssl+/cs sl+	Dybr/b/b/ b	Z/z/z/z	F/f/m/c	N	110+
		Pd057	C	T gn	Coll	M sl/25/tr	g	Msl+/msl +/mscl	Dg/pb/b	Z/z/f	F/c/f	N	130+
		Pd059	C	T gn	Coll	M sl/30/tr	g	Fscl-/fscl- /fscl-	Gbr/b/b	C/c/m	Z/z/z	N	100+
		Pd061	C	T gn	Coll	M sl/35/tr	g	Ffscl/mscl /mscl	B/b/b	Z/z/z	C/z/z	N	100+
		Pd062	C	T gn	Coll	M sl/20/tr	imp	Fscl/fscl/f scl	Gbr/dg/db	C/c/z	Z/z/z	N	100+
		Pd063	C	T gn	Coll	L sl/25/tr	imp	Zicl/zicl+/ vfsc/fscl+	Gb/dg/dg/ b	Ab/m/ab/ c	Z/c/z/z	N	106+
		Pd064	C	T gn	Coll	L sl/25/tr	imp	Fsl+/msl+ /msl+/msc l/csscl/ms cl/	G/gb/dg/d g/dg/b	C/ab/c/ab/ z/z	Z/f/f/f/f/ z	N	130+
		Pd065	C	T gn	Coll	L sl/35/tr	g	Vfsl/fsl+/ mscl/mscl /mscl/cssc l	Lbg/lbg/l bg/lbg/lbg	C/c/ab/ab/ c	Z/z/z/z/z	N	100+
		Pd066	C	T gn	Coll	L sl/35/tr	imp	Fscl/fscl/c sscl/csscl/ csscl/fscl	B/dg/dgb/ dgb/dg/rb	Ab//c/c/c/ c/c	Z/z/f/z/f /z	N	150+

		Pd70	C	T gn	Coll	M ls/20/tr	g	Fsc/vfscl/ vfsl+	Yb/b/b	C/c/c	Z/z/z	N	106+
		Pd072	C	T gn	Coll	M sl/25/tr	imp	Cssl+/fscl /mscl/msc l/mscl	Dgb/b/dg/ vdgb/vdg b	C/f/r/f/c	C/r/z/z/z	Y	120+
		Pd092	C	T gn	Coll	L sl/11/c x	g	Msl/mscl/ fscl/cssl- lcss	G/g/dg/m x	Ab/ab/ab/ mx	F/f/f/c	N	120+
		Pd094	C former	T gn	Coll	L sl/27/tr	g	Vfsl/vfsl+ /vfsl+	Dg/b/yb	Ab/m/m	Z/f/m	N	130+
	22/25/44	Pd096	C	T gn	Coll	L sl/27/tr	g	Vfsl/fsl+/f scl	Dg/dgb/d yb	Ab/ab/c	R/r/m	N	132+
Gumkah a	23												
Dompol ha	24	Pd037	C	T gn	C	M sl/13 /tcx	G	Msl/wr(lf s)	B/dyb	Z/mx(wr)	F/wr	N	46
		Pd040	C	T gn	C	M sl/24 /tcx	g	Msl+stcsl +/ stfsl+	Dyb/dgb/ mx	Ab/z/c	C/ab/ab	Y	90+ but v stony
		Pd041	C	T gn	C	M sl/35 /tcr	g	Fscl/lwr(l cs)/ wr(csl+)	Dg/mx/g	M/mx/mx	C/m/wr	N	59
		Pd042	C	T gn	C	M sl/25 /tcr	g	Wr(Gvcsl 0/wr(cscl) /wr	B/mx/b	C/mx/mx	wr	N	23

		Pd045	C	T gn	C	M sl/11 /tcx	g	Wr(Gvcsl 0/wr(cscl) /wr	B/mx/b	C/mx/mx	wr	N	23
		Pd048	C	T gn	Shall c	M sl/11 /tcx	g	Msl/wr	Mx/dgb	C/mx	wr	Y	43
		Pd050	C	T gn	Shall c	M sl/15 /tr	g	fscl/wr	G/b/mx	Ab/ab/mx	Z/z/wr	Y	45
		Pd052	c former	T gn	Shall c	M sl/25 /tr	g	Fscl+/wr	Gb/mx	Ab/mx	Z/wr	Y	45
		Pd053	C	T gn	Shall c	M sl/20 /tr	g	Zl+/fscl/ wr(gvcsl)	Dg//dg/b	Ab/ab/mx	R/r/wr	N	100
		Pd058	C	T gn	Shall c	M sl/25/tr	g	Msl/fscl/ mscl/mscl	Yb/yb/dy b/b	Ab/ab/c/ mx	Z/c/f/ab	N	58
	24/11/55	Pd093	C	T gn	Coll	L sl/25/tr	g	Msl/lms/c ssl+	Dg/g/dgb	Ab/ab/st	Z/z/wr	N	74
Umtekha	25	Pd028	C	T gn + ?sk	Coll	L sl/10/tr	g	Fscl/mscl/ cscl	Dgb/mx/ mx	Ab/mx/m x	F/f/f	N	130+
		Pd031	C	T gn + ?sk	Coll	L sl/11/t v	g	Zicl/wr(m scl)/wr(fs cl)	Gb/db/rb	Ab/m/c	Z/wr	? dk to 100+	132+
		Pd032	C	T gn + ?sk	Coll	L sl/20/tr	g	Zicl/wr(m scl)/wr(fs cl)	Gb/db/rb	Ab/m/c	Z/wr	? dk to 100+	132+
		Pd033	C	T gn + ?sk	Coll	L sl/20/tr	g	Fscl/	Gb/b/db/d rb	Ab/m/ab/ c	z	Y	110+

		Pd034	C	T gn + ?sk	Coll	L sl/60/tr	g	Fscl/	dyb/drb/dr	z	z	N – too shallow to see	65+
		Pd035	C	T gn + ?sk	Coll	L sl/36/tx	g	Fscl/	rb	Z/f	F/z	N	116+
		Pd043	C	T gn + ?sk	Coll	L sl/20/tx	g	Fscl/	Rb/drb/rb/drb/rb	Ab/m/c/z/z	F/z/z/z/z/z	Y x 2	125+
		Pd049	C	T gn + ?sk	Coll	M sl/23/tx	g	Fscl/	yr/rb	Z/z	F/f	?Y	110+
		Pd067	C	T gn	Coll	M sl/20/tr	g	Fscl-/fscl-/fscl-/fscl-/mscl/mscl	Yb/b/b/b/b	C/c/c/c/c	R/z/z/z/z	N	115+
		Pd069	C	T gn	Coll	M sl/15/tr	g	Vfscl/vfscl/vfsc	Dgb/dgb/rb	C/c/c	Z/z/z	N	105+
	25/11/66	Pd071	C	T gn	Coll	M sl/20/tr	g	Fscl/fscl/fscl/mscl/vfscl	Gb/dgb/b/b/rb	Ab/c/f/m/f	Z/z/z/z/z	N	218+
Radhi	26	PH056	C	Cf	C	Ls/16/st	g	Fsl+/msl-/msl-/mscl-/mscl	Dg/gb/gb/gb/pb	F/ab/m/m/ab	Z/z/z/c/c	N	115+
		PH061	C	C gt	C	Ls/15/cv	g	Msl+/wr (lms(	Dg/mx	Ab/z	C/z	N	61

		PH062	C	T gn	C	Ms/18/r	g	Csl/fscl	Dg/ob	F/z	C/z	N	110+
	26/4/70	Pd079	C	Cf/4/tr	Coll	L sl/4/tr	g	Vfsc/f-mscl/fsc	Mx/b/b	Z/f/c	F/f/f	N	150+
Thara	27	PH053	C	T gn	All	F/5/cv	g	Fsl+/fsl+/fsl+	Gb/dg/dg	M/m/z	Z/z/z	Y	112+
		PH051	C	T gn	F	Mf/8/cv	g	Fsl/csl/msl/fsl	Dgb/dgb/dg/mx	M/ab/c/c	F/f/z/c	Y	115+
		PT004	C	T gn	F	F/10/tx	g	Vfsl/vfscl/fscl/Mscl/msc/csc/cscl/csl+	Dg/dgb/dg/dyb/dg/dgb/b/dbg	C/m/ab/m	Z/f/r/f/z/f/z/f	Prob Y – all dark	109+
		PT007	C	T gn	F	F/10/tv	g	Fscl/mscl/fscl/Msl+/mscl	G/dyb/dg/yb/dg/	Ab/m/ab/c/m/f/c/f	Z/f/z/z	Y x 2	155+
		PT013	C	T gn	F	F/4/tr	g	fsl/msl+/msl/mscl/szl+/mscl	Py/g/dgb/dyb	Ab/m/c/z/c	Z/z/z/f/f/f	?Y	165+
		Pd073	C	T gn	F	Cfan/24/tr	g	Msl/m-cssl	Mx/mx	Wr/wr	Wr/wr	N	76
		Pd074	C	T gn	Coll/f	Cfan/17/tr	g	Lf-ms	Mx	Wr	Ab	N	27
		Pd095	C	T gn	F all	L sl/10/cx	g	Vfsl+/vfsl+/f-msl	Dg/dg/dgb	Ab/ab/z	C/c/m	N	130+
	27/9/79	Pd097 (Kubji)	C	T gn	F all	L sl/hf/22/tr	g	Fsl+/mscl/fsc	Dgb/dgb/dyb	Ab/ab/p	Z/f/ab	N	83+
Hebesa	28												

Yuewak ha	29												
Lungkha	30												
Botala	31/1/80	Pd075	C	T gn	Coll	Ht/55/c x	g	Fscl/m-csscl/cssl +	Db/db/b	Z/r/z	C/f/f	N	146+
Kubji	32	PT005	C	T sk	F	F/7/tx	g	Vfscl/fscl/fsc	Gb/dgb/dr /	Ab//c/f	R/z/f/r	?y	140+
		PT011	C	T sk	F	F/28/tr	g	Fsl/fscl/m scl/csl/fsc	Lbg/dyb/y b/db/gb/rb /dr	Ab/f//f/f/a b/ab	Z/z/zf/f/ f	Y	130+
		PT012	C	T sk	F	F/4/tr	g	Zcl/msl/m sc/ stsc	G/db/yb/y r	M/ab	Z/zf/c/m	?y merging	128+
	32/4/84	Pd098 (Matal ungchu)	C	T gn	F all	F/16/tr	g	Fsl+/fscl/ msl+/f-msc	Dg/dgb/b	Ab/ab/ab/ ab	Z/f/f/f	N	130 +
Shengan a	33	PH054	C	Cf	All	F???	g	Mscl/mscl /csl+	Dg/dg/vd g	Ab/f/f	C/c/c	Y	60+
		PH055	C	Cf	All	F/10/tr	imp	Fsl+/csl+/ gscl	Gb/pb/lbg	C/c/m	C/c/m	Y	63+
		PH058	C	Cf	All	F/18t/r	g	Fsl+/csl+/ csl+/gscl	Gb/g/g/g/ py	F/ab/ab/a b	F/c/c/r	N	88
		Pd076	C	Cf	All	F sl/5/cx	g	Vfscl/vfsc l/vfscl	Dg/vdgb/ b	Ab/m/f	M/c/f	Y	152+

		Pd078	C	Cf	F all	F/10/tr	g	Vfscl/vfscl/vfscl/fscl	Dgb/b/dyb/lob	Ab/c/c/ab	M/ab/ab/m	N	137+
		Pd080	C	Cf	F all	F/17/tr	g	Fscl/mscl/lgs/fscl	Dg/dgb/gb/mx	Ab/r/m/z	F/m/f/z	N	133+
		Pd081	C	Cf	F all	F/6/tr	g	Mscl/m-csscl/csscl	Dg/gb/mx	M/ab/z	C/m/wr	N	145+
	33/8/92	Pd191	C	Cf	F all	L sl/7/cx	g	Vfsl+/fsl+/f-msl+/cssl	Dg/mx/dg/dgb	Ab/z/z/f	C/f/c/c	N	135+
Kanglung	34/1/93	Pd060	C former	Tgn	C	M sl/40/tr	imp	Csscl-/csscl-/msl+	Yb/dgb/g	Z/m/m	C/r/z	N	150+
Gangkha	35												
Bajothangkha	36	PT008	C	mx	Mra	Mrt10m /2/tr	g	Msl/csl/cs/ms/gvs/lms/lfs/ms/msl/csl+/vfs/fsl	G/yb/yb/gb/dyb/g/gb/g	C/m/c/m/z/m/c//z	F/z/c/z/r/c/z/f	?y – alluv. Bands	184+
	36/2/95	PT009	C	mx	Mra	Mrt10m /15/tr	p	Zl/vfslcl/msl/ms/zc/	Gb/dg/g/dg	M/f/z	Z/c	*?y – too wet to see*	*150+ WT @ 60*
Wangjokha	37	PH049	C	Mx	Mra	15mrt2/tr	imp	msl+/msl/csl+	G/dgb/g	Ab/m/m/	Z/z/f	Y	97+
	37/2/97	PT014	C	Mx	Mra	Mrt20m/4/tr	g	Vfscl/fscl/msl/csl/lms/fsl/vfsl/csl/msl+	G/dgb/lob/yb/dg/dyb/b/gb	C/m/c/z/c/	Z/z/f/f/r/z/z/z	Y	176+

Matalun gchhu	38/1/98	PH052	C	Mx	All	30m/15/ cv	imp	Msl/msl/lfs	G/g/dgb	M/m/m/c	C/c/z	Y	102

APPENDIX C Puna Tsang Chhu Village Names

SL. NO.	NAME	SL NO.	NAME
1.	Gamipang		
2.	Dado Geompa		
3.	Palu		
4.	Jarigaong		
5.	Zowdasa		
6.	Chongshikha		
7.	Jashikha		
8.	Domisimu		
9.	Sechekha		
10.	Lamjo		
11.	Thomji		
12.	Gangkha		
13	Nepa Geompa		
14.	Lhaga Gaong		
15.	Tshosa		
16	Garakha		
17.	Shengna Geompa		
18.	Khubji		
19	Manika		
20.	Singchumo		
21.	Lungkha		
22.	Khelekha		
23.	Tana		
24.	Oladama		
25.	Yusegaong		
26.	Jangsarbu		
27.	Minagaong		
28.	Tshebisa		
29.	Changjokha		
30.	Dzomjangu		
31.	Oladama		
32.	Jangmarmu		
33.	Jimthangkha		
34.	Sershong		
35.	Yangchekha		
36.	Gumkarmo		
37.	Gubji		
38.	Tshekakha		
39.	Tshephu		
40.	Khawakha		
41.	Jara		
42.	Jibjokha		
43.	Ongkha		

44.	Bejopangna		
45.	Dagokha		
46.	Lorena		
47.	Khebelok		
48.	Bumtakha		
49.	Tashiding		
50.	Jangkhokha		
51.	Nawakha		
52.	Samthang		

53.	Damchekha		
54.	Botokha		
55.	Wakuna		
56.	Siregaong		
57.	Shoshi		
58.	Girgaong		
59.	Tongchena		
60.	Rungrikha		
61.	Kashikha /Chesigaong		
62.	Zebesa		
63.	Yeuwakha		
64.	Wangshikha		
65.	Lakhu		
66.	Phuntshopelri		
67.	Menchugaong		
68.	Ritsha		
69.	Tongtshana		
70.	Dzomlethang		
71.	Dochokha		
72.	Babegakha		
73.	Thara		
74.	Phulusu		
75.	Lunakha		
76.	Kilekha		
77.	Yongu		
78.	Yebesa		
79.	Hebesa		
80.	Seonagasa		
81.	Talo		
82.	Nobgaong		
83.	Biemina		
84.	Dongkokha		
85.	Labtshakha		
86.	Gyenchukha		
87	Gumakha		
88.	Baemsisi		
89.	Wulakha		
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APPENDIX D