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Final report

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SRA

Opportunities to improve land and water management practices in Bhutan

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1 Acknowledgments

I wish to thank the Royal Government of Bhutan for making my visit possible. The Australian Centre for International Agricultural Research funded the scoping study, and I am grateful to them for their vision and for the assistance provided to me in arranging and carrying out this study. In particular I wish to thank Ms Simrat Laban, Assistant Manager of the Delhi office, for sourcing much of the background information and smoothing my way throughout Bhutan.

Mr Kezang Jamtsho of the Ministry of Agriculture, Bhutan, developed the itinerary and made all local arrangements, and drove us throughout our arduous program. But more than that, he proved to be a deep well of knowledge and wisdom, without which my study would have been very much the poorer. My sincere thanks go to Kezang.

2 Executive summary

This study was commissioned by ACIAR at the request of the Ministry of Agriculture of the Royal Government of Bhutan. It addresses possible actions to improve land and water management in relation to surface water and watershed protection, water harvesting, and improved cropping/ farming practices and systems. It focuses on Eastern Bhutan where poverty levels are greatest. The emphasis was on opportunities for research, but consideration was also given to extension and policy options.

Bhutan lies between China to the north and India to the east, west and south. Elections for its first democratic government were held in 2008. The Kingdom remains largely under forest, which is well protected by strong environmental policies and practices. The Bhutan Water Policy, approved in December 2006, makes particular reference to the potential for water harvesting. Precipitation is high (700 to >5,000 mm/yr), mostly falling in April-October. However, irrigation is needed for high yields of wetland rice because of relatively porous soils combined with insufficient rain during land preparation and transplanting (May-June), and cessation of the monsoon before maturity. But only 12% of arable land is irrigated, with 40% of rice being rainfed (in the Southern Zone).

Land and Water Mangement Issues

Bhutan places high priority on protection of natural resources. Concerns have been expressed in Bhutan about soil and water management issues related to agriculture, but few of these have been investigated. Whilst river water quality is generally good, sedimentation of hydro power stations is a concern, driven by apparent increase in sediment load, said to be of agricultural origin. Changes in land use are perceived to reduce discharge from springs and impact on drinking water in some communities.

Main Findings

Studies are needed to identify and quantify the sources of sediment, with more extensive stream gauging and sampling than at present and at multiple scales. However, land slips are a major contributor to river sedimentation, increased by anthropogenic factors, especially inappropriate road construction practices. A less important contributor is poor maintenance of the canal system used for irrigation water reticulation. Little evidence was seen that arable 'dryland' agriculture contributes to serious gully or sheet erosion, despite the high rainfall, steep slopes and traditional tillage practices. Nevertheless, land is at risk of erosion between the first and second crops in the wet season. Research and extension are needed to develop and promote soil-conserving tillage practices. Poor irrigation water management beyond canals contributes to erosion. This could be addressed through existing water-users groups, if they are given greater support.

There is potential to 'harvest' water in Eastern Bhutan, but other measures could also improve productivity, with the added benefit of reducing land and water degradation.

Water harvesting has the potential to reduce the riskiness of farming associated with variable rainfall, so apart from direct benefits for agricultural production it is relevant to any discussion on climate change.

The integrated development of new tillage methods, crops with maturity better matched to climate, and access to limited (supplementary) irrigation, provide good opportunities to increase productivity, reduce risk, and importantly, to improve soil conservation. Research on soil management should be high priority because of the benefits: soil and water conservation, savings in labour, and potentially higher and more assured yields. Nowhere in the world has this revolution occurred overnight, but where farmers have been involved in participatory research, practical problems have been solved quickly and adoption accelerated. There will need to be strong extension support, and policies to foster adoption, possibly including selected input subsidies.

Bhutan has the capacity to implement improved land and water management practices. The local government system provides for natural resource management groups and water-users groups to develop and implement plans, co-opt outside assistance and access funds for implementation. Extension workers are supported by a network of Research Centres with specialist foci, including horticulture and field crops.

Summary recommendations

Recommendations encompass (i) research for which Bhutan will require external support, (ii) research within current Bhutanese capability, (iii) extension and (iv) policy.

Of the research options requiring external support, priority should be given to a review and if necessary adoption of wider national water flow/quality monitoring program, including necessary stream gauging, to identify and quantify sediment sources. This will underpin any improvement to water policy and watershed protection programs. Priority should also be given to developing the technology for zero/minimal tillage to manage erosion, and to developing related policies and programs to facilitate adoption.

Any policy to promote water harvesting will require research (with external support) to develop design principles, but this should be preceded by more thorough water balance modelling and an economic assessment to substantiate the expected benefits.

An important topic for consideration that is within the capability of the Bhutanese is a thorough, systemic assessment of nitrogen constraints in farming systems. There is evidence that N is a bigger constraint than is generally appreciated. Improved rice N-nutrition in the Southern Zone should prove especially beneficial.

The body of the Report provides a table summarising 14 recommendations.

3 Introduction

3.1 Background

3.1.1 Overview of Bhutan and Objectives of the Scoping Study

This scoping study was commissioned by ACIAR at the request of the Ministry of Agriculture of the Royal Government of Bhutan to provide guidance on possible actions to improve land and water management.

The Royal Kingdom of Bhutan (pop. 753,000) lies strategically between China to the north and India to the east (Arunachal), west (Sikkim) and south (Assam, West Bengal). Elections for its first democratic government will be held in 2008.

The Kingdom remains largely under forest, which is well protected by strong environmental policies and practices. The National Environment Protection Act (2007) is the umbrella for environment protection. The Bhutan Water Policy was approved in 2006. This enlightened policy treats land and water in terms of multifunctional landscapes. With these policies, Bhutan should remain a highly significant global conservation area whilst setting the stage for effective watershed development. The Water Policy makes particular reference to the potential for water harvesting.

Figure 1. Bhutan and its neighbours

There is little abject poverty in Bhutan[1], but 31.7% of Bhutanese lived below the national poverty line in 2004, mostly in rural areas of Central and Eastern Bhutan, where more than half the families are classified as food-insecure. Eastern Bhutan is less well developed than the West, providing fewer income-generating opportunities to meet a food deficit. Migration to urban centres is creating a shortage of labour, which must be accounted for in developing new farming systems. There are opportunities to expand production in niche areas.

Precipitation is high (700 to >5,000 mm/yr), with most falling in from April to October. However, irrigation is needed for high yields of wetland rice because of the relatively porous soils combined with insufficient rain during land preparation and transplanting (May-June) and cessation of the monsoon before maturity. However, only 12% of arable land is irrigated, with 40% of rice (the Southern Zone) rainfed because of failure of the irrigation infrastructure.

Concerns have been expressed in Bhutan about the contribution of agriculture to land slips and soil erosion. Concern has also been expressed about land degradation on the

[1]Poverty Analysis Report Royal Government of Bhutan (August, 2004). ‘Abject’ poverty was recognised only recently.

remaining areas of ‘shifting’ agriculture, and also the sustainability of cropping on the very steep hill slopes which comprise the majority of the ~8% of arable land in the Kingdom. There is also a perception that land use change from either forest or perennial-based systems to arable, annual cropping has reduced discharge from ‘springs’, affecting drinking water supplies in some communities. Few if any of these concerns have been thoroughly investigated.

The report is based on a visit to Bhutan from 24 May to 3 June, 2007 which included meetings with Government officials and a journey of 1,400 km by road which included visits to research centres and meetings with extension officers and farmers and water-users groups. Relevant policy documents were also read. The study focused on Eastern Bhutan where poverty levels are greatest.

3.1.2 Objectives: Terms of Reference and Deliverables (ACIAR)

1. Overview available policy documents to develop an understanding of the overall framework for water resource development, management and protection.
2. Consult with key stakeholders from research, extension, and other government and community organisations in Bhutan to understand linkages between policy, institutions, user groups and current constraints they face for improving land and water management practices.
3. Analyse institutional capacity for research and extension to provide technical information to support better land and water management practices.
4. Prepare a report for ACIAR which will make recommendations to the Royal Government of Bhutan on possible actions for improved land and water management practices specifically in relation to :

- surface water and watershed protection
- water harvesting and the catchment water balance
- improved cropping/farming practices and systems
- improved water use and water use efficiency.

3.2 Report format

Findings from the study are presented in two sections, first in extended background information (Sections 3.3 - 3.8) and then the 'Key results and Discussion' (Section 6) which are reported against the specific objectives given in Section 3.1.2 Paragraph 4, above. Section 4 provides the Methodology. Sections 5 and 7 are not applicable to this scoping study. Section 8 reports Conclusions and Recommendations.

3.3 Climate and Agro-ecology

Precipitation in Bhutan is high (700 to >5,000 mm/yr), with most of it falling between April and October (Fig.2). It is the high rainfall combined with its seasonality that led the Ministry of Agriculture to request support from ACIAR for a scoping study around the opportunities for water harvesting, although set in the wider context of improved land and water management. Precipitation is higher at lower elevations and tends to increase again at the highest elevations, where low temperature is a major constraint to plant production.

At lower altitudes, social factors, including difficulty in controlling grazing, are more important constraints to cropping in winter than is the low temperature.

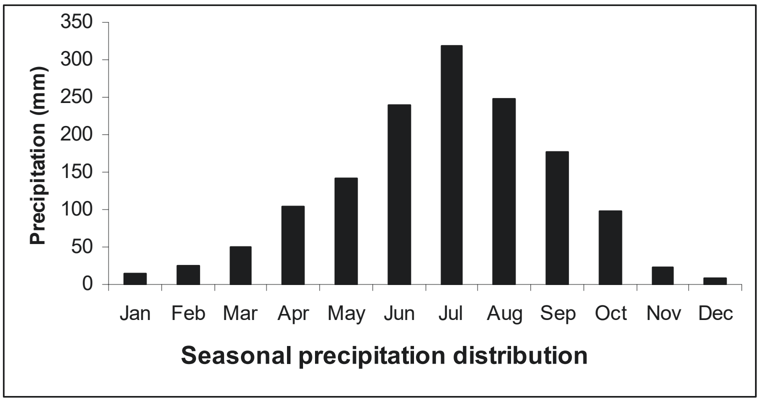

Figure 2. Average monthly rainfall for Bhutan – (for all 16 Districts (Source: MoA, Appendix 2)

The physical geography of Bhutan has resulted in a wide range of agro-ecological zones (Fig. 3) with significant differences in farming systems (described in the next section) and the dominance of particular crops in each zone. Six main agro-ecological zones are distinguished on the basis of temperature and rainfall, both of which are affected by altitude.

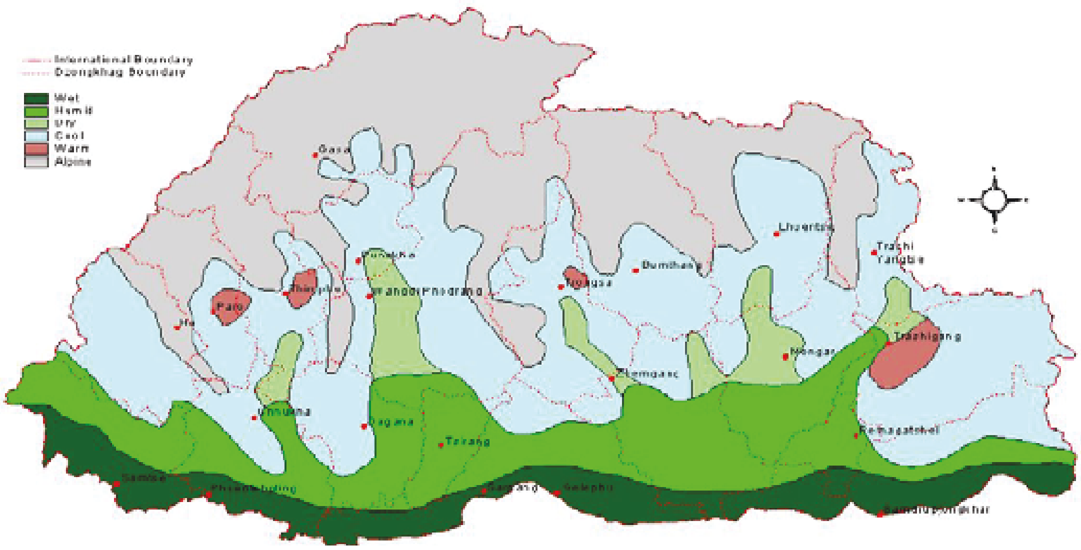

Figure 3. The agro-ecological zones of Bhutan (See Gyamthso, 1996, Appendix 3)

The alpine zone (~3,600-4,600 m) has mainly tundra vegetation. The region is mostly covered in snow and has low population density with only nomadic yak herders operating the livestock system as their sole source of livelihood. Movement of animals to the lower sub-tropical area starts in November – December, returning in April.

The Cool Temperate Zone is at high altitudes (2500-3600m). Rainfall is relatively low. 'Dryland' (rainfed)[2] farming is common but livestock are the main feature of the farming system. Pastoralists maintain herds of yak and sheep on summer alpine pastures, migrating down to about 3,000 m in winter. Crops are grown in the short spring-summer period, or winter-hardy species may be planted in autumn for harvest in spring. Whilst extensive grazing provides the bulk of the feed requirement, crop residues are an important fodder in winter.

[2] In Bhutan, rainfed cropping is referred to as 'dryland' or khamzhing. Rice is grown in 'wetland' or chuzhing, which is mostly valley bottom land receiving supplemental irrigation supplied by an extensive network of canals, often fed from local streams.

The Warm Temperate Zone (1,800-2,500 m) enjoys slightly higher temperatures than the cool Temperate Zone, although frosts occur. Semi-nomadic herders keep pigs, poultry, horses and small ruminants. Cattle graze on stubble after crop harvest. Rice straw is used as winter fodder for the cattle. During winter, crop residues are the only feeding option. In wetland, rice is grown in summer, followed by wheat, potatoes or vegetables in winter. Rice is mostly the traditional red type. The use of improved tools and farm machinery is increasing (e.g. power tillers).

The Dry Subtropical Zone. Temperatures are higher than in the other temperate zones. Cattle are tethered on paddy land and maize fields after harvest, for manure. Rice is the main summer crop in 'wetland' areas, which may be followed by irrigated vegetables, wheat or mustard. In 'dryland', maize and mustard are the main crops. Improved varieties, fertilizers and herbicides are increasing, but farm yard manure (FYM) is still the main source of nutrients for crops.

The Humid and Wet tropical zones fall within 150-1,200 m and have good areas for crop cultivation. Livestock rearing is normally stationary - cattle for milk production and draught power are tethered in cropping areas prior to land preparation, for manure. FYM or compost based on manure and leaf litter are the main fertilisers. Due to scarcity of maize fodder, crop residues are fed to cattle. The main cropping pattern in the wetlands is rice followed by wheat or mustard as in the dry subtropical areas. A third crop is sometimes possible. Due to high rainfall and humidity there are more insect and disease problems in crops. Citrus (mandarin types, locally called "oranges") is an important cash crop. In 'dryland', maize is the main.

3.4 Agriculture and farming systems

One-third of the GDP of Bhutan is related to agriculture, including forestry. It is essentially subsistence agriculture, and provides the livelihood of some 80% of the population (Togbay[3]). Staples are rice, maize potatoes and buckwheat, with smaller areas of mustard, various pulses and small areas of vegetables in home gardens irrigated from drinking water. There appear to be opportunities to expand production in niche areas such as citrus and high-quality vegetables (there is an abundance of low-quality cheap product from India), including organically produced vegetables and herbs. Bhutan enjoys an out-of-season advantage in horticultural trade with India, but much of the value of production is captured too far down the value-chain (Tobgay[3]). Opportunities for trade will improve as a direct road link from Eastern Bhutan (Mongar) to India is under construction, and improved rail links within India are planned to connect with major arterial roads in southern Bhutan.

Agriculture is a land-use system with five components, all of them used by most farmers: *sokshing* (public woodlot for private use), *chuzhing* (wetland cultivation), *kamzhing* (dryland), *tseri* ("slash and burn") and *tsamdro* (natural pasture/grassland). Rainfall and temperature, both related to elevation, together with topography, determine the proportions of each component in any area. The design of farming systems is shaped by climate, family food requirements, the need for sufficient fodder for livestock (especially cattle) and an ingenious system of managing crop nutrition.

Sokshing

This is a public woodlot on which individuals or a community have user rights for leaf-litter, fodder and firewood. It is a local resource management institution. It is at the

[3] Agricultural diversification in Bhutan (2005) Sonam Tobgay, Ministry of Agriculture, Bhutan. Also Bhutan and the WTO: A Study on the Impact of Agriculture and Agriculture-Related Issues in WTO Agreements on the Bhutanese Agriculture Sector. Sonam Tobgay November, 2006.

heart of soil fertility management wherever cropping is practiced[4]. Leaf litter and pine needles provide bedding and the decomposed litter and farm yard manure (FYM) make fertiliser for the cropping systems. Even in warmer months, cattle are tethered to ensure litter and manure is composted for use as fertiliser. In effect, nutrients and organic matter are harvested at low rates over a large area of forest (and from crop residues) and concentrated on small areas of crop. This composted FYM is often applied at quite high rates (10t/ha). Sokshing should ensure the return of P, K and carbon to cultivated soil, but N may be low because the forest litter will be low in N. Much depends upon the ratio of litter to manure and the animal diet. There appears to be no concern about the possible rundown of macronutrients in the sokshing woodlots and possible subsequent effects, which I found a little surprising. New legal provisions are gradually transforming sokshing from a private to a public resource. Prior to the Forest Acts of 1969/1995 and the Land Act (1978) the person registering sokshing in his name owned it. The heritable nature of sokshing resulted in much fragmentation. Possible adverse consequences of the change in land tenure to public ownership were not examined in this scoping study.

Chuzhing

Chuzhing or (wetland) is valley cultivation on slopes <30% that are terraced and irrigated from an extensive system of canals that are installed and maintained privately, with some government oversight. Canal maintenance is often poor. Canals are gravity-fed, mostly from local streams. There is no oversight of water reticulation beyond the canal. Chuzhing is mainly found in the valleys of Paro, Wangdue and Punakha. Elsewhere, such as Trashigang, Mongar, Lhuentse and Trongsa, chuzhing it is only found scattered on steep slopes. Paddy rice is the major summer crop grown in wetland and the main winter crop is wheat. Paddy can also be grown twice in a year. Buckwheat, potatoes, maize, pulses and vegetables are minor winter crops. Irrigation appears to be necessary for paddy, but not in neighbouring West Bengal, because of highly porous soils and uncertainty of rains at the beginning of the monsoon.

Kamzhing

Khamzing or (dryland) is terraced or un-terraced rainfed agricultural land on >30% slopes. It comprises around 50% of the cultivated land in Bhutan, and is the main focus of the Scoping Study. The "terraces" are the natural result of years of cultivation or other anthropogenic activities, rather than being purposely constructed. The terraces, often associated with hedgerows or like vegetation on the cross slopes, commonly break longer slopes into short flow pathways for runoff. The depth of the topsoil is said to be ‘shallow’ (e.g. 5-8 cm), although it appeared from roadside cuttings and other exposed profiles, that soil and rock in different stages of decomposition could generally be found to much greater depths. Moreover, primary tillage was said to be very deep, up to 30 cm (using a plough dawn by 2 bullocks[5]), which is unlikely if topsoil depth is 5-8 cm.

It is difficult to estimate or generalise about the plant water holding capacity of such soils, but it is certainly more than the few millimetres implied by stating soils are shallow (5-8 cm). Maize is the major summer crop in most areas, followed by buckwheat in areas unsuited to maize due to cold summers. Wheat, barley, mustard,

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[4] Sangay Wangchuk, Head of Nature Conservation, MoA, Thimpu, provides an interesting description of Sokshing in: Wangchuk S (2002). Local Resource Management Institutions: A Case Study On Sokshing Management. Journal of Bhutan Studies: 7: 61-81. See also Walter Roder (1990), Agriculture Research Centre Yusipang P.O. Box 212, Thimphu, Bhutan; and Roder et al (1992) Shifting cultivation systems practised in Bhutan Agroforestry Systems 19: 149-158.

[5] Cultivation costs per maize crop were estimated to exceed A$100/ha, providing a strong economic case for reducing cultivation and using herbicides to control weeds.

pulses, buckwheat and potatoes are common winter crops in maize growing areas. Soil fertility management is through the use of compost based on sokshing. Traditionally, pulses have been intercropped with maize at elevations up to around 2,000 m, at least in the second crop where two maize crops are grown in succession. This practice seems to be decreasing. Although published figures put Bhutan at the very bottom for rates of fertiliser use internationally (<2 kg/ha/yr[6]), anecdotal evidence was that rates of N fertiliser are increasing, especially for maize. Where fertiliser is used, it is as a supplement to manure and compost. Given the approach to soil fertility management it would not be surprising if crops were N-limited. Given the apparently low-N diet fed to tethered cattle, protein (or N) deficiency may also be an issue for them. Herbicides do not appear to be used at all. The options for crops and crop sequences in "Dryland" systems are summarised in Table 1, but opinion varies widely on the systems practised.

Tseri

slash-and-burn 'shifting cultivation' practised mostly by subsistence farmers in the east and east-central dzongkhags of Chhukha, Samtse, Bumthang, Zhemgang, Mongar, Trashigang, Jongkhar and Pemagatshel to hedge against crop failure and compensate for food deficit. Tseri areas are cultivated on a rotational basis with an average fallow period of 5-6 years, being shorter in subtropical areas and longer in temperate areas. Land is fallowed (not cropped, but with a good cover of vegetation) to allow regeneration of vegetative cover and soil nutrients. Common crops are maize, millet, wheat, barley and buckwheat. Other crops are grown as inter-crops. Tseri areas are generally located inside or adjacent to forests, so crop depredation by wildlife is high. Tseri is discouraged for environmental and economic reasons, and suitable alternatives are being explored and promoted. It was my impression, however, that the tseris I saw were not all a serious environmental problem, given the long 'pasture' phase between crops which allows a good period for recovery of soil fertility. A variation of the practice is pangzhing, with scant tree cover and short-fallow rotation. It seems to be more risky.

Tsamdro

This is natural pasture/grass land, on which individuals or a community have grazing rights. Limited land holding is a major constraint in production of sufficient fodder for livestock leading to over-grazing causing a decline in grassland production and conflicts amongst communities. Through dialogue and facilitation, efforts are being made to evolve by-laws that provide a clear prescription of the roles and responsibilities of members of the grazing community.

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[6] One example is for the 1998 data: http://earthtrends.wri.org/text/agriculture-food/country-profile-22.html

Table 1. Common crop options and sequences: Low (<600 m), Medium (600-1800 m) and High (>1

Elevation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct
Low Social issues constrain cropping in Jan		Maize			first maize crop		Harvest Sow		2nd maize	
		Maize			first maize crop		Harvest Sow		2nd maize	Harvest S
		Maize					Harvest		Sow	
Medium Social issues constrain cropping in Jan			Maize		first maize crop			Harvest Sow	Second maize	
			Maize		maize			Sow	Mustard secon	
High Low temperatures constrain cropping in Jan-Feb			Maize						Buckwheat	
					Winter wheat/Potatoes (harvest)					
					Mustard		(spring type, may follow Pot)			
									Mustard	(w
					Mustard (as winter crop)					

Notes on Table 1

These elevation categories differ from the FAO AEZ approach, but are consistent with usage in Bhutan (eg Dukpa 2006 J. Renewable Resources 1 (2) p76.

Maize is limited to about 2,600 m elevation. The second maize crop in a year is generally intercropped with warm-season pulse (soybean or kidney beans etc). The cho
and soil fertility. The same factors together with the type of other crops grown as intercrops with maize or in rotation with maize determine the length of the fallow period a
cultivation means that a substantial quantity of crop residue is available for fodder (see www.fao.org/ag/AGP/AGPC/doc/Proceedings/Tapafon02/tapafon4.htm for extens

Short-season mustard varieties are needed for the 3-crop option to be viable

Vegetables are grown at all elevations in small home plots using drinking water for irrigation. Three-crop option with irrigated vegetables means larger scale of productio

Cold temperature limit applies mainly to maize and warm-season pulses. Wheat and potatoes may over- winter at higher elevations

3.5 Land and Water Degradation in Bhutan

The State of the Environment Report (Bhutan 2001) notes that important factors contributing to land degradation are: loss of vegetation due to deforestation, over cutting beyond silviculturally permissible limits, unsustainable fuel wood extraction, shifting cultivation, encroachment into forest land, forest fire, over grazing in the forests, extension of cultivation onto lands of low potential or high natural hazards, non-adoption of adequate soil conservation measures and improper crop rotations. Loss of vegetation due to pressure on forests is one of the main factors. The demand for construction timber by the domestic sector, although not well documented, is only partly (20%) met from managed forests. The traditional rights of the people to forest produce and unauthorised harvest by farmers both exert pressure on the forests, particularly close to settlements. Similarly, fire wood extraction from forests exceeds silviculturally permissible limits, resulting in depletion of forests and degradation of forestland.

Extensification as well as intensification of agriculture, to offset the deficit in food requirement, face serious constraints because expansion of arable land is not possible and the nature of the terrain makes enhancing the productivity of cultivated land difficult. At the same time converting forests to agricultural land is generally undesirable. Livestock rearing, especially of cattle, is an important rural activity. The estimated cattle population of the country is 300,000 and the number is likely to increase along with human population. Grazing of this number in forest areas, thought to be far beyond the carrying capacity, exerts great pressure on forest land with resultant degradation.

3.5.1 Agricultural Contributions to Land and Water Degradation

Agriculture, excluding forestry for my study, has been linked to a range of environmental concerns in Bhutan, the more important of which are discussed briefly, below. Few if any of the cases where agriculture is thought to impact on soil erosion or hydrology have been thoroughly investigated.

Surface water quality in Bhutan a decade ago was generally found to be very good in a limited water quality sampling program intended to establish a baseline for subsequent systematic water quality assessment[7]. The only significant issues at that time were associated locally with urban development. I could not locate any subsequent original reports on water quality, although the 2001 State of Environment Report noted that there was still only limited information available on the quality of freshwater resources in Bhutan, and referred back to the 1997 baseline study for data. Other recent publications have done likewise12. The Department of Power under the Ministry of Trade and Industry has set up sampling stations to monitor and collect flow and water quality data, but again I did not have time to access any data. There appear to be about 5 major sampling sites in East Bhutan, covering all major streams.

Despite what seems to be a lack of data on water quality, concerns have been expressed about the contribution of agriculture to land slips, which are the main causes of river sedimentation12. Concerns have also been expressed about the contribution to sedimentation from erosion of agricultural land. I found no reports with measured rates of soil erosion from different land uses.

The main focus of concern about water quality in Eastern Bhutan is siltation of the hydro power station on the Kuri Chu (at Mongar). At the time of my visit the river at the main crossing near Mongar, 2 km upstream from the power plant, carried a heavy silt load (or,

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[7] Water Management in Bhutan. Earth Observation in service of water management. Bangkok, Thailand September, 2006

rather, high turbidity) despite this being the end of the dry season when flow would have been derived from base flow and snow and glacial melt, none of which should carry significant silt or nutrients as there is no runoff from erosive rainfall. A nearby tributary was not turbid, as expected. Sediment in the main channel of the Kuri Chu apparently originates from remote catchment areas. According to anecdotal reports, it is generated far upstream where there is little or no arable agriculture in Bhutan. Studies are required to verify the source of sediment and determine if it continues throughout the year contributing a base load of pollution. As the wet season advances and temperatures also rise, flow in the river will increase due to runoff and increased glacial and snow melt (estimated[8] to be a factor of about 4). It is not possible to say what the relative contributions to sediment load might be at the peak of the monsoon, i.e. the ongoing 'base load' and the monsoon-initiated erosion from within Bhutan. It is possible, however, that sediment concentrations may decrease at high river flows if monsoon-initiated inflows have lower concentrations than the flow comprising what I have termed the 'base load'.

Given that arable agriculture is only 8% of the total area of Bhutan, and <8% upstream from the power plant at Mongar, the contribution of arable agriculture to sediment loads will be relatively small compared with the apparent year-round loads generated in the upper reaches of the Kuri Chu where no agriculture is carried out in Bhutan. This does not mean that agriculture makes no contribution to sediment loads, but it makes the case for further investigation of the sources of sediment, and to put the relative source strengths of pollution into perspective. These observations and conclusions are relevant to Eastern Bhutan. Different situations may pertain elsewhere.

3.5.2 Land slips

Land slips are relatively common in Bhutan, depending on the underlying geology. The relative importance of contributing factors has not been established, but a major predisposing factor is the concentration of surface or sub-surface flows caused by inappropriate road construction practices. In the photograph of khamzing (dryland) agriculture below (Fig. 4), two gullies ('A') can be seen passing through an agricultural area. Both gullies were initiated by land slippages at a road, indicated by arrow B. [Note the relatively short flow lengths created by the small fields (arrow C).]

Figure 4. Land slip and subsequent gully erosion initiated by road construction

The following photograph illustrates erosion in a sub alpine area initiated by poor road construction practices (arrows show 3 sites), one of many examples.

[8] K. Jamtsho

Figure 5 Soil erosion resulting initiated by road construction in sub-alpine forest (see arrows)

I observed two instances where land slips may have been associated with agriculture, both occurring in the extremely wet conditions of 2004 when slips were common in Eastern Bhutan. One was quite spectacular, shown below. A reason for uncertainty about the origins of this progressive land slip/erosion is that a slip has been initiated on the far right of the photo, where no arable agriculture appears to have been practiced. [Again note the short flow lengths within arable fields.]

Figure 6. Major slips and gully erosion possibly initiated by agriculture

Although the causes of land slips and the magnitude of surface erosion are not known, the government of Bhutan commendably has been active in promoting ‘best bet’ remedial measures. Land slips are a reminder of the fragility of this environment and the need for great care when introducing new land management technology, such as water harvesting.

A less important contributor to land slips than road construction is poor maintenance of the canal system used for irrigation water reticulation.

Note that, of necessity, my field trip did not visit all potential erosion sites in Eastern Bhutan. Some districts may have a greater predisposition to agriculture-induced slips than I observed.

3.5.3 Soil Erosion

The State of the Environment Report (Bhutan 2001) notes that it is mainly in the mountainous terrain that human-induced activities trigger soil erosion. It notes that one of the prime reasons for land degradation in Bhutan is putting land to use for which it is not suited. This is mostly due to excessive pressure on land resource but also due to ignorance about the consequences of improper land use. The report points out that adoption of land use according to land capability should ensure that land is put to appropriate use. It notes that one way of achieving this would be to develop land capability classes based on the USDA model and modified through research and available technology to suit national conditions. However, the report acknowledges that land capability according to the USDA model cannot be the only criterion for restricting the use of land, as most of the land in Bhutan is moderately to steeply sloping and has been mapped as available only for non-arable use. It notes that this is in conflict with the current land use in most areas of the country and any attempt to apply it would be unrealistic, socially undesirable and impracticable. Instead, ways must be found to permit food crop production to continue on such lands with scientific and technical backing to guard against the possibility of degradation. Encouraging farmers to change land use, or to modify land management practices, would normally be more efficient than imposing restrictions.

Soil erosion in 'Wetland'

In the wetland system where land is terraced and bunded primarily for rice production, there is often no provision for excess water (tail-water) drainage, and uncontrolled movement of water has on occasion given rise to formation of gullies, although on my journey of 1,400 km by road I saw little evidence that tail-water drainage was a serious issue. Where it is an issue it can be managed by well established soil and water conservation measures through the Water User Groups operating at geog level (described later in this report). Figure 7 shows a relatively steep slope with wetland (terraced) rice with no sign of gully formation or of sediment deposition at lower elevations.

Figure 7. A 'wetland' area showing no signs of major erosion.

Soil erosion in ''Dryland'

Concern is rightly expressed about soil erosion from practising arable dryland agriculture on steep slopes in high rainfall areas. Steep hill slopes comprise most of the ~8% of arable land in Bhutan. However, I saw little evidence for gully erosion, caused by arable agriculture. The single, minor example is shown below. This field was relatively large for Bhutan and had a relatively long flow length, which may have contributed to the erosion. Shallow, minor gullies and rills may be erased by cultivation, adding to an illusion of low erosion rates, and yet no evidence was found for local deposition of sediment to suggest this was happening to a significant degree.

Figure 8. An uncommon occurrence: visible gully formation in ‘dryland.

Sheet erosion

This is likely to occur but leave no sign as obvious as gullies. Any signs of sheet wash or rilling would be removed by subsequent cultivation. However, I inspected many sites and found no evidence of significant sediment detention where it might be expected if sheet wash and rilling were a big issue. In the maize field below, any significant sediment would build up along the hedgerow (right, centre) that would intercept runoff and filter coarse sediment. Such hedgerows are good land mangement practice, even where erosion rates appear to be low.

Figure 9. Maize on steep land with no sign of erosion or sediment build-up at edge of field

The two fields below similarly showed no sign of gully erosion, rilling, sheet wash or sediment deposition, despite the convergence of runoff into flow lines which had been cultivated. It would be good soil conservation practice to encourage such drainage lines to remain vegetated.

Figure 10. Steep cultivated field with flow convergence with potential for major erosion.

Figure 11. Maize on steep slopes with flow convergence but no serious erosion evident.

3.5.4 Conversion of land use

There is also concern in Bhutan about steep land with shallow soils being converted inappropriately to arable agriculture. Improved productivity of existing arable land would reduce the pressure for conversion. These issues are considered in more detail later in this report.

3.5.5 Shifting agriculture

Concern is expressed about land degradation on the remaining area of ‘shifting’ agriculture but, as noted earlier, these may be seen as wide rotational systems; i.e. low cropping frequency. Soil fertility mangement seems to be sound, with the low cropping frequency and a modified shopzing system in which litter is gathered and burnt and spread on the site to be cropped.

3.5.6 Reduced discharge in local springs

Declining drinking water supplies due to reduced discharge of springs is a serious issue in some communities. Several professional staff expressed the view that changes in land use from trees/shrubs to pasture and annual crops had reduced the discharge. This is an unlikely explanation, which runs counter to other international experience. An alternative explanation is that a change in rainfall amount and/or distribution is the driving force. Farmers in Bhutan (as in India, Europe and Australia) spoke about changes in rainfall having led to a more risky environment in both spring and autumn. This is consistent with predictions of climate change. Whether linked to climate change or not, small shifts in seasonal rainfall may account for big increases in risk, and further justifies investigation of the benefits of water harvesting.

3.6 The ecological significance of Bhutan

Bhutan has the highest percentage of land under protected area and forest cover in Asia and is in the top 10 countries with the highest species density in the world: 7,000 species of plants, 165 species of mammals and 700 species of birds. About 26% of the country is in protected areas, plus 9% biological corridors created to connect different protected parks (Fig. 12).

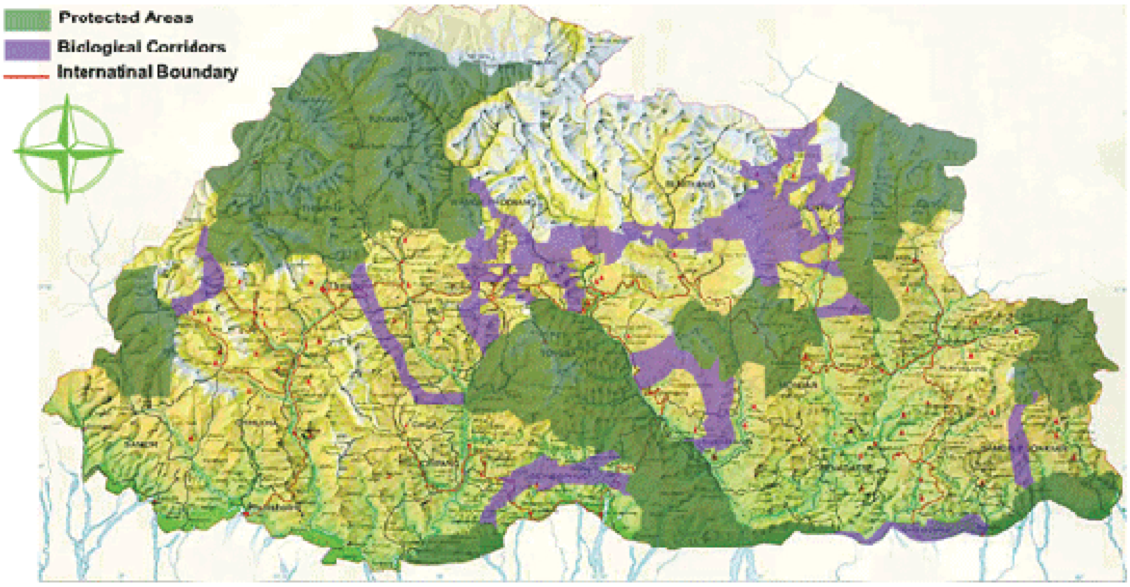

Figure 12. Biodiversity Conservation: Protected Areas and Corridors (Source: Bhutan Dept of Tourism)

The Royal Government has designated 29% of its total land area as protected areas. The protected area system in the country comprises four national parks, three wildlife sanctuaries and a nature reserve. To facilitate the free and uninhibited movement of animals and birds within a wide natural range, the nature reserves, parks and wildlife sanctuaries are connected through biological corridors that take up an additional 9% of the country's territory. Bhutan has four national parks, four wildlife sanctuaries, and one strict nature reserve, which was established in 1993. In 13 of the 20 districts, biological corridors connect these protected areas and enhance wildlife migration.

3.7 Rural Poverty

Bhutan experiences little abject poverty, but 31.7% of Bhutanese lived below the national poverty line in 2004[9]. These people are concentrated in rural areas of Central and Eastern Bhutan where more than half the families are food-insecure (Fig. 13). Eastern Bhutan is less well developed than the West, so income-generating opportunities to meet a food deficit are limited. Migration is creating a shortage of labour, which must be accounted for in developing new farming systems.

[9] (Poverty Analysis Report, Royal Government of Bhutan, Thimpou. August 2004)

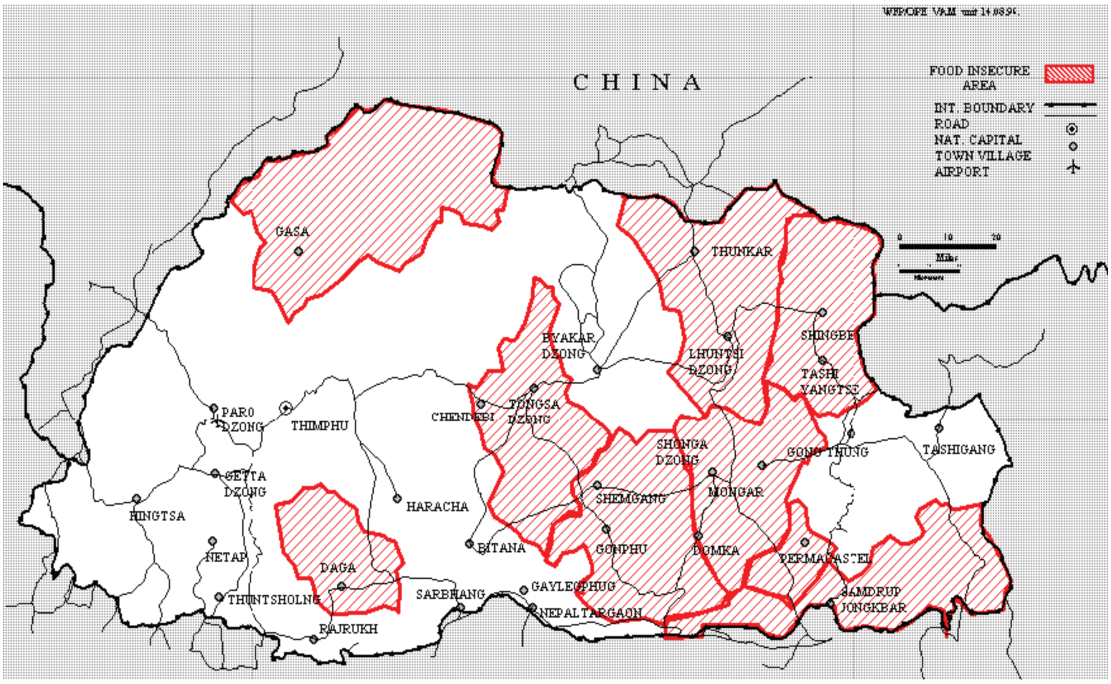

Figure 13. Food insecure areas in Bhutan (Source: World Food Programme)

3.8 Reasons to consider water harvesting with land management

Water harvesting has the potential to increase food security for the poorest farmers, to increase cash income or reduce cash expenditure for other farmers, and to increase agricultural productivity and export earnings or replace some imports. Several government documents, in particular the Water Policy, refer to the potential for rainwater harvesting and the importance of using water more efficiently. The policy notes that only 78% of the country's population has access to safe drinking water and only about 12.5% of the arable land is irrigated. Given the high rainfall and runoff in Bhutan which evokes the interest in water harvesting, one must ask why irrigation is so important when rainfall is so high. Or, as an alternative to providing more irrigation, can agronomic management be improved so that the water which infiltrates and is retained in the root zone of dryland crops (against drainage) and used more efficiently?

Farmers in Bhutan are totally dependant on tillage for weed control and to prepare seedbeds. Until now, the revolution in tillage practices that has swept the rest of the world has passed Bhutan by. In part this seems to reflect a desire to minimise costly and potentially harmful inputs. The cost of tillage and high labour requirement, however, are creating an environment where reduced tillage or no-tillage systems will be considered by farmers. Bhutan has no expertise in this area, although it has quite strong agronomic research and extension capability.

Many studies world-wide have shown the potential for improved cultivation practices to improve water use whilst reducing soil degradation. Improved land management reduces dependency on tillage and has the potential to improve soil water relations making it easier and safer to sow crops early and to minimise the time between successive crops in the wet season. This means that the second crop can finish earlier with less likelihood of running short of water in lower rainfall areas (thus increasing yield). Earlier harvest of the second crop should create an opportunity for a third crop in higher rainfall areas. In this way improved land management can increase crop yields and reduce risk. In effect, this increases water use efficiency of the dryland crop. It can increase crop productivity without any more irrigation. It is the agronomic alternative to the 'engineering' solution of rain water harvesting. Changes in crop varieties and improved plant nutrition may be needed to achieve the higher productivity made possible through improved tillage. Reduced dependency on tillage requires substantial new management skills.

Reduced tillage should also help to maintain soil structure and reduce the risk of erosion which, given the steep slopes of cultivated land, would seem to be a priority.

Where reduced cultivation allows timelier sowing of crops and creates the opportunity for a third crop, this could justify providing irrigation based on water harvesting. The idea would be to use harvested water to supplement water already in the soil at the end of the wet season. Supplementary irrigation could be used to establish crops that could not be planted otherwise. Crops would subsequently grow on residual soil water, with limited or no further irrigation.

Research on soil management should be a high priority because of the benefits it will bring in terms of soil and water conservation, savings in labour, and potentially higher and more assured yields. However, it should be noted that nowhere in the world has this revolution occurred overnight. Although (in my experience) where farmers have been involved in participatory research, practical problems have been solved quickly and adoption accelerated.

4 Methodology

- Review of relevant documents provided by ACIAR, including policy documents.
- Interviews with senior public servants in Bhutan.
- A hosted field trip to view problems in the landscape, meet researchers (at two research centres), farmers and extension workers.
- Simple water balance modelling whilst in Bhutan to scope out the water harvesting possibilities.

Figure 14. Route taken (in black) to inspect field sites, meet farmers and visit research centres, showing dzongkhags (Base map: Bhutan Dept. of Tourism)

A participative approach was taken during the review, to ensure observations and conclusions were appropriate.

5 Key findings and discussion

5.1 Renewable Natural Resources Policy

The Kingdom remains largely under forest which is well protected. Bhutan is strongly committed to the principle and practice of integrated watershed management. The National Environment Protection Act (June 2007) is the umbrella act for environment protection. The national water policy (Bhutan Water Policy, Appendix 1) was adopted in Dec. 2006. It treats land and water in terms of multifunctional landscapes, although there is no environmental services scheme15 that would help share the cost of environmental management. The Act makes particular reference to the potential for water harvesting. With these policies, Bhutan should remain a highly significant global conservation area. These strong environmental policies and practices should ensure that Bhutan remains a highly significant global conservation area.

Five Year Plans are the main instrument for achieving national policy objectives. The Five-Year Plans, which spell out programmes, activities and budget outlay, are formulated and implemented at three levels: the central level made up of sectoral plans; dzongkhag level; and geog level. The current Ninth Five Year Plan is unique in two ways. First, as the first Five Year Plan following the conception of Bhutan 2020, it provides an overarching policy for development based on the concept of “Gross National Happiness”, which underscores economic, spiritual and environmental well-being as equally important, and that Bhutan needs to balance these aspects for overall development. It provides a 20-year perspective of development goals and objectives. Environmental conservation is one of the five main development objectives, including combating land degradation as an inherent development strategy. The second unique feature of the Ninth Plan is that it departs from central-based planning to a geog-based participatory planning approach, in keeping with national policy on decentralization and giving increased powers and responsibilities to locally elected community. The Ninth Five Year Plan, with a Cover Note on poverty reduction, also serves as the country’s Poverty Reduction Strategy Paper. The Tenth Five-Year Plan will vest substantial financial resources with the Geog.

Below is a list of some of the key policies of relevance to water management in the context of the broader development policy framework of Bhutan.

The National Environment Strategy (“The Middle Path”, 1988)

This was derived through an inter-sectoral and consultative process. It seeks to balance environmental conservation with economic development. The Strategy enshrines the concept of sustainable development and identifies three main avenues for such development:

1. Hydro power development based on integrated watershed management
2. Agricultural development based on sustainable practices
3. Industrial development based on effective pollution control and environmental legislation.

This scoping study is set within the context of the first and second of these. Agriculture is linked to hydro power by a need to minimise sediment loads in rivers feeding the power stations. The Water Policy adopts the forward-looking approach of the ‘multi-functional landscape’, in which clean water, biodiversity conservation and religious and cultural ‘values’ sit beside hydro power generation, forestry and agricultural production as functions or ‘products & services’ provided by the landscape. This provides Bhutan with the capability to introduce an environmental trading or offset scheme in which environmental benefits are assigned a monetary value and farmers who provide an 'environmental service' are paid to do so. Such schemes have not been developed, but the Policy hints at this and steps have been taken in that direction with, for example, farmers being compensated for crop damage suffered from wild life.

Recommendation 1. That the Royal Government of Bhutan investigates the feasibility of introducing an environmental services scheme[10]

The National Environment Strategy directly addresses areas of special importance for environmentally and culturally responsive economic development. These are tourism, roads, financing mechanisms for sustainable development, public health, urbanization, gender and natural resource management, environmental impact assessment, and population. It identifies five key cross-sectoral needs that must be effectively addressed to integrate environmental considerations into economic development planning and policy-making. These needs pertain to information systems and research, institutional development and popular participation, policies and legislation, training and education, and monitoring, evaluation and enforcement.

The National Forest Policy (1974)

This places priority on conservation of forests and associated resources for their ecological values. Economic benefit from forest resources is considered secondary and is to be derived within sustainable limits. There are four guiding principles:

1. Protection of the land, its forest, soil, water resources and biological diversity against degradation, such as loss of soil fertility, soil erosion, landslides, floods and other ecological devastation and the improvement of all degraded forest land areas, through proper management systems and practices
2. Contribution to the production of food, water, energy and other commodities by effectively coordinating the interaction between forestry and farming systems
3. Meeting the long-term needs of Bhutanese people for wood and other forest products by placing all production forest resources under sustainable management
4. Contribution to the growth of national and local economies, including exploitation of export opportunities, through fully developed forest based industries, and to contribute to balanced human resources development through training and creation of employment opportunities.

The Water Policy

This is clear in its support for water harvesting, but within a broader environmental context and integrated watershed management. (See Appendix 1).

Agriculture Policy

Development is guided by the overall Renewable Natural Resources (RNR) sector policy which outlines the following objectives:

1. To pursue a people-centred development path that would lead to the realization of their aspirations for a better life through active public participation in the development process
2. To pursue economic development that has prospects for long-term sustainability based on the country's resource situation, comparative advantages, and community based self-help

[10]http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/EXTEEI/0,, content MDK:20487926 ~menuPK:118 7844~pagePK:210058~piPK:210062~theSitePK: 408050,00.html

3. To pursue a balanced and equitable development of the country's renewable natural resources and distribution of benefits accruing from them across society and regions
4. To adopt development strategies that are environment-friendly and ensure the integrity of the country's fragile ecosystem
5. Sensitivity and responsiveness to cultural heritage, ensuring its preservation
6. Government is aware of subdivision and alienation of land from agriculture through real estate speculation. Land consolidation policies aim to maintain agricultural land in economic units.

5.2 Capacity

5.2.1 For Agricultural Research and Development

The Ministry of Agriculture (MoA) and the Council for RNR Research: the MoA was formed in 1985 drawing together agriculture, livestock, development and forestry sub-sectors, which are now collectively known as the renewable natural resources (RNR) sector. MoA has also instituted a Council for RNR Research to guide and coordinate research programmes and activities implemented by the regional RNR Research Centres, of which there are four. Apart from the Departments of Agriculture, Livestock and Forestry, the Ministry includes the Department of Survey and Land Records, National Biodiversity Centre, Information and Communication Services, and Bhutan Agriculture and Food Regulatory Authority.

The key functions of the MoA are to develop agriculture, livestock and forests for the benefit of the Bhutanese people through a continuous research and development process; raise the living standard of rural people through promotion of agro-based income generating activities, reduction of farming drudgery, improvement of nutrition and health, and access to services, market and information; protect the natural environment through sustainable and judicious use and management of its land, water, forest and biological resources; and ensure food safety through preventive and mitigation measures.

Department of Agriculture (DoA): conducts studies on soil capability and land hazards, management of irrigation drainage systems; introduces soil conservation measures and promotes Slope Land Agriculture Technology (SLAT).

Department of Livestock (DoL): promotes stall-feeding and manure management, different uses of grazing land, pasture improvement in non-forest and barren lands to reduce overgrazing and degradation in state forests, and facilitates rotational grazing in improved pastures.

Department of Forest (DoF): promotes integrated approaches to sustainable forest management in relation to resource-based ecosystem management; facilitates the development of community and private forestry to produce fuel wood, fodder, and timber; conducts studies on forest functions and carrying capacities and tenure systems for grazing land.

Department of Survey and Land Records (DSLR): provides cadastral, land registration and records, digital mapping and map publication, and survey and mapping services to all agencies.

The Council of RNR Research of Bhutan (CoRRB): conducts research on RNR, including forestry, field crops, horticulture, livestock and farming systems.

The National Soil Services Centre (NSSC): leads soil and land management research activities of the MoA. It works through the regional research centres of the CoRRB and Dzongkhags under the Home Ministry to provide technical and advisory services. The

NSSC is made up of a Soil and Plant Analytical laboratory, a Soil Survey unit, a Soil Fertility unit, and a Soil Microbiology unit.

A new journal was launched in 2006, the "Journal of Renewable Resources, Bhutan". It strives to be a quality journal providing an outlet for good research which is relevant to Bhutan and its neighbours. This is an excellent initiative that will play an important role in developing the capacity for research and development in Bhutan.

5.2.2 Capacity to Implement Policies and Programs

Governance is outlined in Figure 15. Bhutan has been a monarchy since 1907. The Druk Gyalpo-the king-is Head of State and head of government. King Jigme Khesar Namgyal Wangchuck is the Head of State. A gradual process of decentralization was started in 1981 by establishing the District Development Committee (DYT) to promote people's participation in the decision making process at the district level. Later, the Block Development Committee (GYT) was established to allow decision-making at grassroots level to promote socio-economic development strategies and programs as per community needs and aspirations. In 1998 the king reduced the scope of his absolute powers, and now formally rules with the advice of his government. In 1999, a 10-member body called the Lhengye Zhungtshog (Council of Ministers) was formed and given executive powers. Legislative power is vested in the government and the National Assembly. The country will introduce parliamentary democracy in 2008. The Government is comprised of 10 Ministries:

The system of governance is founded on a policy of decentralisation and community empowerment, which provides the country with ready capacity to implement policies aimed at improved land and water management. It is based on the Geog (Block) which is comprised of 5-15 villages. Blocks are administered under the dzongkhags or Districts, of which there are 20. The dzongda (Head) is assisted in discharging his development functions by the Dzongkhag Development Committee which consists of people's representatives and government officials representing various sectors. This approach to governance provides a basis for identifying development opportunities that are locally relevant and well supported. If watershed development research and development were to be undertaken in collaboration with the Ministry of Agriculture and/or Renewable Natural Resource Research Centres, it is at this level that local approval, planning and implementation would occur, ensuring broad community participation and likely adoption of research outcomes.

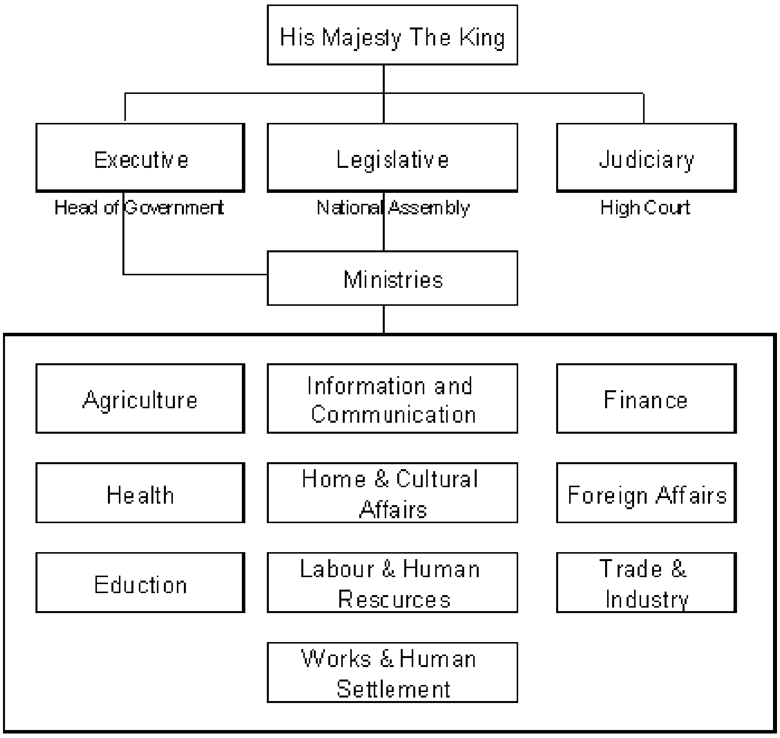

Figure 15. Governance structure

At geog level, the Gup (Head) is assisted in development matters by a Geog Development Committee, supported by extension workers in agriculture, forestry and livestock. These Committees can form specialist groups such as Water-users Associations (WUA) or other NRM groups, and they can co-opt additional assistance where needed. These bodies have access to funds for program planning and implementation, 30% of which they control directly.

As an example of the importance placed upon the geog, WUAs operating under the geog have been promoted as a vehicle for the participation of beneficiaries in the construction, renovation and maintenance of irrigation canals. The formation of WUAs is a prerequisite for seeking government assistance in the water sector. Government assistance to the irrigation sector has been redefined, with three basic principles: meaningful farmer participation, support to Water User Association's, and multidisciplinary teamwork. Despite the importance of WUA's, they need ongoing professional support. Extension in the water resources/watershed management area came from a large number of water specialists up until 2003, but now comes from agricultural advisers who have little experience or training in water issues. There appears to be a case here for either reorganisation of staff to provide specialist support for the WUA's, or professional development of the agricultural extension workers.

Extension is supported four Research Centres with specialist foci. Research Centres at Wenghar and Bajo have national mandates for horticulture and field crops.

5.3 Specific Objectives and Recommendations

5.3.1 Surface water and watershed protection

This issue is driven primarily by concerns about sedimentation of hydro power stations, but there is also a strong measure of environmental protection. I was not made aware of any data that supports the contention that sediment loads are increasing, or that any particular human activity is responsible. With respect to the Kuri Chu at Mongar, it is impossible to determine the relative importance of agriculture (excluding forestry) as a sediment source relative to other land uses and natural geomorphological processes (see Section: Agricultural contributions to environmental degradation). To do so will require research.

Determining sources of sediment.

Given that sources of sediment have not been identified and erosion rates have not been quantified, high priority should be given to this. Geochemical and radiometric sediment tracing techniques should prove effective for identifying sources of sediment, but this will need to be complemented with a flow gauging and water quality monitoring program to establish erosion rates from different classes of land use and geomorphology. Funding for tracing work may be available for the International Atomic Energy Agency in Vienna (contact Dr M L Nguyen, email M.Nguyen@iaea.org). Some gauging and water quality data are available, but I did not see them. Even recent (2006) publications refer back to 1997 data[11]. There needs to be a review of any current monitoring to determine if the number of sites and their location is adequate to quantify the contribution to sediment loads from different land uses.

Modelling water quality.

I do not believe any current empirical models can be used credibly to predict erosion rates or water quality without local data for calibration. Physics-based models will also require much more data for parameterisation or validation than is presently held in Bhutan (or almost anywhere else at catchment scale). There will be no substitute for hard data obtained from a monitoring and research program, as noted previously. Fewer gauging stations and less intensive data collection are required to monitor long-term changes in flow or pollutant concentration than are required to parameterise, calibrate and validate models. When reviewing any current monitoring program, it is important to determine that sufficient high quality data for model parameterisation, calibration and validation will be obtained. Fortunately, there is a network of weather stations providing at least 20 years of weather data, although again I did not see this.

Making use of existing data.

There may be something to learn from turbidity readings in the Kuri Chu at Mongar, if such data are available over at least a five year period. The aim would be to formulate hypotheses about the link between land use/land management and water quality by studying the patterns of variation in relation to rainfall events and the seasonal cycle of land-use and land management, especially those changes that might affect soil erodibility or rainfall erosivity and hence sediment mobilisation. Thus, for example, is there a rise in sediment concentration at the onset of the monsoon then a fall to low levels in August-September, as reported to me for rivers in western Bhutan? If this fall does occur, it would occur when land is being cultivated for the second maize crop, at the height of the monsoon, so the land is both highly erodible and rainfall at its most erosive. This would not make sense if arable agriculture was the main source of sediment.

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[11] Water Management in Bhutan. Earth Observation in service of water management. Bangkok, Thailand September, 2006

Recommendation 2. That any existing flow gauging program be reviewed to determine if both flow and water quality data are adequate for empirical model development.

If the existing program is inadequate, then a network of sites should be established to monitor flow and automatically sample for pollutant analysis.

Recommendation 3. To identify the relative importance of sediment sources in the landscape (including measurement of erosion rates from arable areas), and to prioritise remedial action based on the size of source and cost/ease of remediation.

Much of the research should be suited using radiometric or geochemical tracing techniques, in which Australia has substantial expertise, but expertise and funding may also be available from the International Atomic Energy Agency (Vienna).

Land slips

Serious land slips are quite common in Bhutan. The relative importance of contributing factors such as land use or land management practices has not been established, but a major predisposing factor is undoubtedly the concentration of surface or sub-surface flows caused by inappropriate road construction practices. Concentration of sub-surface flow is caused by inadequate drainage leading to high hydrostatic pressure and sudden failure of soil, commonly overlying rock. Concentration of surface flows may have similar effects if water ponds and saturates soil. Drainage rate of the sub-surface is presumably also a determinant of failure, as well as underlying geology. Thus some districts may have a greater predisposition to agriculture-induced slips than I observed.

A less important contributor is poor maintenance of the canals that reticulate irrigation water. Responsibility for maintenance rests with the community, but Water User's Groups need greater support to perform this role, as noted previously. Note that low rice yields in the southern zone (<1 t/ha) is due in part to failure of the irrigation system, and an analysis of the problem by Karma and Ghimiray (2006)[12] recommends substantial investment of resources in improving/providing the necessary irrigation infrastructure. This will be a matter for policy.

Recommendation 4. That water-user's groups be given the responsibility and resources to plan, monitor and manage the performance of water reticulation beyond the canal system.

Only one or two instances were seen where land slips may have been associated with a change in land use from trees/shrubs to pasture or annual cropping. Change in land use should be considered in any wider investigation of the causes of land slippage, but on the evidence I saw it would not be given any special priority for action except for the most marginal tseri land (or more seriously pangzhing) proposed for conversion to 'dryland'.

Soil erosion

There was little evidence that arable agriculture contributes to serious gully formation or sheet erosion in 'dryland' areas, despite the high rainfall, steep slopes and use of traditional tillage practices. This is a counter-intuitive observation and was certainly not expected. Reasons for this include:

- high permeability of surface and sub soils
- low rainfall intensity (mostly)

[12] Karma and Ghimiray, M (2006) J Renewable Resources, Bhutan 2 (1): 93-114.

- dry soils at the onset of the monsoon - infiltration capacity (as well as rate) is high
- high rates of organic matter return to soil, maintaining soil structure and infiltration
- experience has probably taught farmers to minimise opportunities for surface flow to concentrate (eg by keeping flow length short, commonly within the small fields).

Nevertheless, land is at unnecessarily high risk of erosion between the first and second crops in the wet season when rainfall is greatest, soils are saturated and cover is reduced to zero by tillage. There is a strong case for developing reduced and zero tillage techniques including stubble retention. However, crop residue retention for soil conservation will compete with other uses for residues, most importantly stock feed. Also, steep slopes will preclude much of the zero tillage technology used elsewhere, and there is an understandable reluctance amongst farmers to embrace agricultural chemicals. Overall, the adoption of zero tillage will require significant investment in research and extension. On the other hand, tillage costs are very high and labour is increasingly scarce, so herbicides for weed control should be an attractive option to reduce costs, given sound research and extension. A policy consideration will be the place for short-term financial incentives to support adoption of appropriate technology, for which there are precedents in Bhutan (eg subsidy on selected farm machinery) (See Tobgay 2006).

Recommendation 5. That research be undertaken into protection of arable land between the first and second crops in the wet season, when risk of erosion is greatest.

Minimal tillage will reduce labour costs and remove a major barrier to adoption of improved farming systems. When practiced throughout the cropping cycle this should also increase yields (see Recommendation 12). This research will need to address issues of competition from stock for crop residues (use of fodder crops?) and the steep slopes that will limit some options for mechanisation (machinery options need to be reviewed and may need research).

Poor management of irrigation water reticulation from canals does contribute to gully erosion. This is a management issue (not research) which should be addressed by appropriately resourced water-users groups (see Recommendation 4).

5.3.2 Water harvesting and the catchment water balance

Water Balance estimations

The viability of water harvesting can be evaluated by calculating the soil water balance and estimating: periods when soil water is available for growth, the irrigation requirement, and the expected runoff/drainage, part of which may be ‘harvested’ to meet a shortfall in precipitation. First approximations of these were possible with limited data provided by the MoA and a very simple model described below. First, the monthly water balance was calculated by subtracting monthly reference evaporation (EO) from rainfall (Appendix 2). This is commonly calculated as a simple indication of the months in which rainfall is adequate or not for plant growth but it fails to account for the water holding capacity of soil, which acts as a reserve in dry periods. Nor does it estimate potential losses in runoff and/or drainage. To estimate these, we calculate the cumulative soil water deficit (SWD). SWD at any time is the difference between the potential available water capacity (PAWC, the upper limit of available soil water) and the actual available soil water (ASW), calculated with the equation:

ASW2 = ASW 1 + R - (ET + RO + D), where

ASW2 is plant-available soil water at time 2 (the end of a time-step eg a day or a month) (mm)
ASW1 is the available water at the beginning of the time step (mm)

R is rainfall (mm)
ET is actual evapo-transpiration (mm)
RO is surface runoff (mm)
D is drainage beyond the rootzone (mm), assumed to enter shallow local or deeper regional aquifers and emerge as baseflow.

Assumptions and sources of error

Estimation of runoff could be made using an assumed 'Curve Number' but there is no basis for deciding what the CN might be in Bhutan.

PAWC was assumed to be 150 mm, so the SWD will vary between zero when the soil is wet and 150 mm at the lower limit of plant water extraction. When SWD at the end of an accounting period (in this case each month) is zero, any positive balance of water is said to be available for runoff or drainage. If the SWD is negative at the end of an accounting period, the maximum being -150 mm in our case, then the negative value is the irrigation requirement for a fully irrigated crop. The value of 150 mm assigned to PAWC is the most likely source of error in this modelling exercise. 150 mm applies to many soils and is based on 15% v/v available water over 100 cm root depth. It may be higher in clay soils and much lower in light textured or very stony soils. Some soils in Bhutan are quite stony, and for these sites the soil water store will be over-estimated and RO/D under-estimated.

ET was assumed to equal reference evaporation (EO) during the wet/cropping season because the soil surface will be continuously wet after onset of the monsoon (a necessary simplification given the shortage of actual data). Similarly, weeds were assumed to grow between crops during the dry period ('fallow') and to maintain full groundcover, so ET=EO unless SWD =150 mm, at which point it is zero.

Any uncertainty about starting soil water is removed by starting the calculations in August when water deficits are always likely to be zero.

Crop physiologists consider that 2/3 of this water is readily available, and 1/3 is 'available' but crop growth rates are reduced when a plant draws on this water. Irrigation requirement was estimated as the water needed to maintain ASW >100 mm if a crop was present. For small plants this will be an over-estimate.

Monthly precipitation, the monthly water balance, and the approximate cumulative soil water deficit for three example districts are given in Fig. 16. Precipitation data are the composite of many stations and do not represent the location by the same name.

An obvious difference between the districts in Fig. 16 is the variation in the number of months when average rainfall exceeds reference evaporation. For any location for which the Mongar data are representative (915 mm average rainfall), there are only two months of the year in which rainfall on average exceeds evaporation, and another two where they are about equal[13]. In contrast to this, at sites represented by the Pemagatshel data, rainfall (2094 mm) meets or exceeds evaporation on average for 9 months of the year, and it is not much in deficit for the other three months.

The cumulative soil water deficit reveals more about the availability of water for crop growth and the irrigation requirement than does the monthly water balance. For locations represented by the sets of data in Fig. 16, the soil holds at least some available water in 7, 8, and 12 months (i.e. water deficits are less than 150 mm).

[13] Note these are averages, and years of greater and lesser availability will occur.

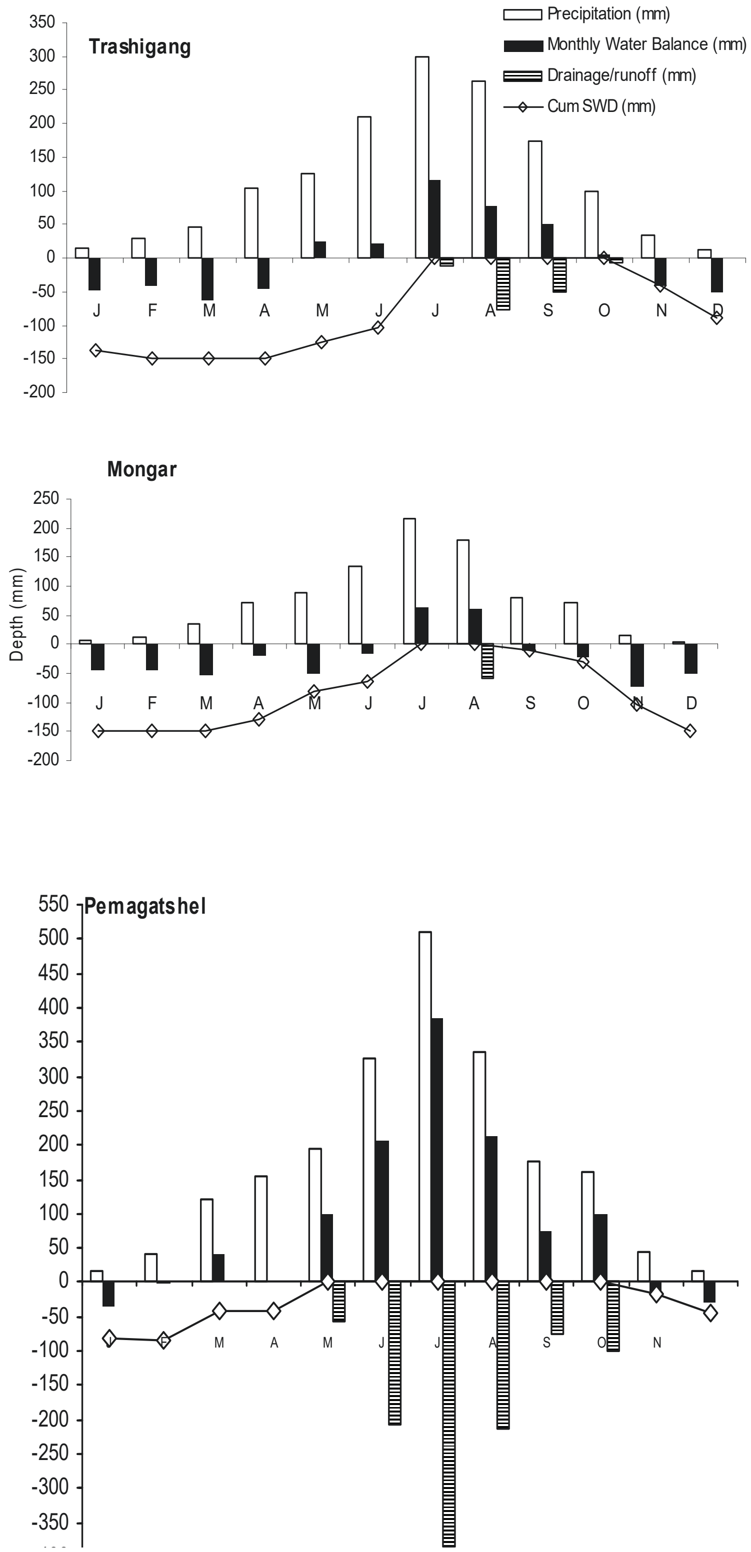

Figure 16. Average monthly precipitation and water balance (P-E_O, see text for explanation) for three Districts (not towns of the same name; refer to map in Appendix 2), and the approximate cumulative soil water deficit/surplus (SWD). All data expressed as depth (mm)

Agronomic interpretation of these observations requires consideration of the annual cropping cycle (Table 1). For example, at mid elevations, the first maize crop at sites with rainfall like the Trashigang district average (1,413 mm average rainfall) will be sown in March. The second maize crop will be harvested in November. From Fig. 16, maize crop 1 will be sown on pre-monsoon showers which, whilst seeming to be plentiful (~50 mm), will not in fact provide much buffering against subsequent dry periods. Farmers know well that these crops are very prone to drought. They will be especially vulnerable to any increase in rainfall variability associated with climate change. Under these circumstances, minimum tillage and crop residue retention, that increase infiltration and reduce soil evaporation, may enhance soil water to the point where the risk of drought to young plants in crop 1 is significantly reduced.

Note again that the data used here are averages for both district and time, and they do not capture the variability of rainfall with both location and year. Some years will be drier than average, but as a general observation, dry average soil conditions indicate greater risk of drought.

At Traqshigang, crop 1 will be harvested in July, when the soil is wettest. Cultivation then takes place leaving the soil bare of cover and in a tilled condition at the time of year when the soil is wettest and rainfall is greatest, creating a potential erosion risk. This risk would be greatly reduced by practicing reduced tillage with residue retention, although it should be appreciated that these technologies require development and considerable farm management skill. A major consideration will be the competition for crop residues, especially for stock feed, as discussed previously.

Grain filling of crop 2 takes place under increasing water deficit, but by harvest in November there may still be quite a lot of water remaining in the soil. This residual water could be used by a third crop, except that the soil is too dry in the surface to permit establishment. However, a single irrigation (from harvested water) may allow establishment, and the crop could then be grown on water remaining in the soil after crop 2.

An important implication of this soil water analysis is that reduced cultivation between the two maize crops could shorten the interval between them and allow crop 2 to mature with more certain water supply. Furthermore, if the maize varieties were slightly quicker maturing, at least for lower-rainfall locations, risks to the second crop could be further reduced. With reduced tillage and quicker maturing varieties, the opportunity to take a third crop becomes more realistic, provided some irrigation is available for crop establishment. The third crop would make use of the last of the monsoon rains and substantial soil water reserves.

At wetter, warmer sites typified by Pemagatshel (district average of 2,094 mm rainfall), soil water deficits are on average never great. Even in February crops could be sown on relatively small falls of rain with little risk. There is clearly the potential to grow three crops a year, as some farmers do, although the water deficits suggest that in drier years crop yields or quality might be affected by short-term drought. Some supplementary irrigation here might provide more stable yields and improve the quality of crops like citrus, as suggested to me.

At locations typified by the Mongar district average rainfall (915 mm) we would expect substantial irrigation to be necessary for any crop production outside the main monsoon period.

These predictions are based on analyses of climate averages. Years of greater and lesser rainfall will occur. More thorough analysis using daily rainfall for individual sites (not district averages) over several years (~20) is needed. These data appear to be available. Further modelling would also identify potential strategies for most effective use of ‘harvested’ water.

Overall, this analysis suggests that the integrated development of new tillage methods, crops with maturity better matched to climate, and access to limited (supplementary) irrigation, provide a very significant opportunity to increase productivity, reduce risk, and importantly to improve soil conservation.

The challenges to this are formidable, and include the value placed on crop residues for fodder and steep slopes that preclude some of the technology associated with ‘conservation tillage’.

The above analysis indicates the agronomic potential to use rainfall more efficiently and for supplementary irrigation. Questions arise of whether there is enough water to harvest and the implications for the catchment water balance. This is the hydrologic potential.

5.3.3 Water Harvesting

Is there enough water to harvest?

In Fig. 16, the water shown in any month to potentially drain or run off is the water that may potentially be harvested, on average. The surprise is that sites represented by Mongar have so little water to harvest. This analysis suggests an average of only 59 mm in combined runoff and drainage, despite quite high and seasonal rainfall (915 mm). It is because of the relatively high evaporation in summer months over much of Bhutan. Although precipitation exceeds evaporation in two months, much of this ‘surplus’ is required to fill the soil water deficit from the previous year and is not available for either runoff or drainage. At such sites, we would only expect significant runoff or drainage to occur in wetter years, unless the soil has been degraded by poor soil management and infiltration rate has been severely reduced. With respect to the discharge of springs, a small drop in rainfall in July and August would be sufficient for springs to dry up. At the other extreme, sites with the Pemagatshel average rainfall will have abundant water to harvest, with runoff/drainage exceeding 1,000 mm. Sites like Trashigang may have water of the order of 150 mm to harvest, on average.

The amount of water that can be harvested obviously depends on the area contributing water to the harvesting structure as well as the depth of water that can be harvested. An example is given here for Trashigang average rainfall, and assuming runoff is to be collected in small in-ground water storages. If a farmer were to aim to capture and hold just 2% of average rainfall (~30 mm or about 20% of the average drainage/runoff) from a catchment area of 0.5 ha (the land under their management), he would require a tank or tanks with a storage capacity of 150 m^3 (eg 5 tanks, each 15x2x1 m). Methods of water harvesting are considered later.

These predictions of potentially harvestable water are approximations only, designed to provide a preliminary evaluation of the potential for water harvesting. They need to be repeated with site-specific rainfall and evaporation data. (Evaporation data will need to be estimated as there appear to be no measured data.) Ultimately they will require experimental quantification.

A key objective in any future research on soil surface management and water harvesting should be to quantify runoff losses, although values will be highly variable at the scale of small plots.

How useful would the water be?

Assume a farmer had been able to store 150 m^3 of water, as in the example above. If a crop sown in early November were to be irrigated with this water, ~100 mm irrigation would be required to overcome the combined average November and December rainfall deficit (R-EO) . Thus a crop area of 1,500 m^2 could be irrigated. Any such crop would grow on residual water stored in the soil following the monsoon (up to 150 mm), current rainfall (on average about 50 mm), and irrigation (say 2 applications of 50 mm each), a total of about 300 mm. This amount of water should be enough to produce about 3 t/ha of wheat or barley, or 1.5-2.0 t/ha of a suitable pulse or oilseed. We would expect the soil profile to fill by August/September in almost every year, even in a 'poor' monsoon, so half of the water required for a reasonable yield is already in the soil, suggesting that supplementary irrigation might be a low-risk, potentially high return strategy.

Whether the yields and crop area estimated above would justify the cost of the water harvesting tanks and the ongoing costs of crop production will depend on the crops to be grown, their market value (and the overall size of the market), and the farmer's own preferences. During my field trip I came across varied opinions about how any harvested water might be used, although all discussants believed that any harvested water would be valued highly for irrigation.

Market assessment and social research would be a pre-requisite for any request for funding to develop water harvesting, regardless of location and the perceived opportunity to capture runoff. Nevertheless, even a modest target of capturing 20% of average runoff/drainage would yield enough water for what appears to be a useful area of supplementary irrigated crop, in areas with the Trashigang district average rainfall.

Further considering a location like Trashigang, observations of surprisingly low erosion rates, combined with high infiltration rates, suggests that much of the water available for either drainage or runoff actually drains rather than run off. If some of this drainage could be collected from shallow groundwater, then it may be made available for irrigation. Whether or not it can be captured depends on geology (and slope) which could not be investigated here, but anecdotal reports are that even short streams may maintain some baseflow for up to several months after the end of the monsoon, at least in medium to higher rainfall areas. This baseflow is being fed by shallow drainage and it should be possible to capture some of it. This possibility is considered later.

As one might expect, the locations with the most water to harvest (like Pemagatshel) are the best endowed with rainfall and in least need of additional water unless it is to establish a third crop, reduce water-related variability in yield or to improve product quality.

What about more marginal locations than Trashigang?

Water harvesting at Mongar may still be possible, despite low apparent runoff or drainage. With similar calculations as for Trashigang, the analysis of Mongar district average rainfall leads to a further important point. Given normal climate variability, there will in reality be no water to harvest in some years, and in others much more. No water harvesting scheme should lull farmers into thinking that water would always be available to harvest in locations with rainfall like the Mongar district average. However, within Mongar District there will be locations with higher rainfall where there is more water to harvest than shown here.

This analysis cautions us against assuming that water harvesting is possible everywhere.

Effects of water harvesting on the catchment water balance?

If water is 'harvested' and lost as ET there is obviously less water for drainage/runoff. The less water there is to harvest, the bigger the potential impact on the catchment water balance. Any effects of water harvesting on the catchment water balance at the regional scale are likely to be small because the area of intervention relative to the total watershed will be very small. However, the preliminary modelling described here shows that in areas which are marginal for water harvesting, significant effects on local discharge after the monsoon are possible. It has been suggested that springs are drying up in some areas because of land use change from perennial plants to annual crops, suggesting that water is marginal in these locations. Whilst I do not think this explanation is probable, there is little doubt from anecdotal remarks that discharge from some springs has declined and that water harvesting has the potential to worsen this.

Where rainfall is not marginal for water harvesting, there will still be effects on the catchment water balance, although they may not be important either locally or regionally. However, they should be established in any research to develop water harvesting principles and practices.

Water harvesting may be combined with other measures to increase recharge during the wet period, when runoff is high, and later extract this water as discharge. This approach would slightly reduce high flows in the monsoon, which is not likely to be a problem, but allow water to be extracted later without major effect on low flows. Such a strategy would need to be tested experimentally. The results will be heavily influenced by soil type, soil management and underlying geology/hydrogeology, as well as rainfall and other climatic variables. Reduced tillage with crop residue retention is one possibility for increasing recharge through improved land management, which may be augmented by 'gully plugging' as practiced in India (caution as high flows will be hard to control and failed attempts will lead to soil erosion). Once water has been added to the shallow groundwater there are possibilities of extracting it from the baseflow which it later feeds (see below).

Some people interviewed during the scoping study thought that small, lined surface storage storages could be used to harvest small amounts of runoff. Thoughtful design may allow these structures to operate as recharge points early in the monsoon, if infiltration and redistribution of water are limiting factors in recharge, and as water storages later.

The results in Fig. 16 indicate the potential to significantly reduce outflows by directing more water to ET rather than runoff or drainage. More thorough investigation of this potential impact is required, initially through water balance modelling, but ultimately using experimentation to provide the data to properly parameterise and validate the model used. Although impacts on runoff/drainage may be relatively small, it is possible that cleaner water may result if runoff is reduced by changes in surface management (eg reduced tillage, appropriate bunding etc) and more water is subsequently added to groundwater and discharged as baseflow. This could have the dual benefits of providing more water after the monsoon for either drinking or irrigation, and reducing total sediment loads entering the rivers. These theoretical possibilities require multidisciplinary field investigation including expertise in hydrology/hydrogeology, agronomy and soil management/soil conservation.

5.3.4 Conclusion to the water balance study

The water balance calculations revealed significant opportunities to 'harvest' water and increase crop production which, in principle, should contribute to much-needed economic development in Eastern Bhutan. The greatest amount of water that can be harvested is in higher rainfall areas (generally lower altitudes) where the need for irrigation is least, but even here water harvesting for irrigation may improve the yield and quality of citrus, for example. In somewhat lower rainfall areas at medium altitudes, there appears to be considerable scope to harvest water and use it as supplementary irrigation for crops that would subsequently grow on residual water following the wet season. In lower-rainfall areas, small amounts of water could be used to irrigate small areas of high value crops, in the first instance vegetables, although it appears that water harvesting in such areas may be risky.

Water harvesting will alter the local water balance, especially local recharge/discharge relationships, but the actual responses cannot be predicted. Effects will likely be most important during and after recession of the monsoon. Effects on runoff in the monsoon and deep drainage to regional aquifers should be small, except in low rainfall areas of Bhutan.

Given the very preliminary nature of the water balance modelling reported here, and both the opportunities and potential costs associated with water harvesting which have been identified, I recommend further, more thorough modelling using site rainfall data rather than district, improved estimates of ET, and refined estimates of PAWC based on soil texture and 'stoniness', with sensitivity analysis. The magnitude of benefits certainly justifies further work to provide greater certainty. Further modelling work should also identify the locations where water harvesting is most likely to be viable, and to identify agronomic strategies worth exploring in later experiments.

Recommendation 6. That more detailed desk-top water balance investigation be undertaken to carefully quantify the opportunities for water harvesting.

This investigation should be combined with studies to identify the best market opportunities, including cost/benefit analyses. Together, they will provide sound estimates of the potential costs and benefits of implementing water harvesting (including production for home consumption to avoid cash outlays).

This study (with some participation of stakeholders, especially farm families) should take no more than several person months and require little or no external funding and assistance. It would underpin any application for external funding for research on water harvesting. Any application for funds would be further enhanced with an estimate of the area suited to water harvesting, approximated using GIS modelling of land slope, elevation and rainfall.

5.3.5 Approaches to water Harvesting

Three approaches to water harvesting were identified.

1. Better use of residual soil water, achieved by improved agronomic management and judicious use of harvested water to improve crop establishment during recession of the monsoon.
2. Capture of runoff water during the wet season in small, plastic-film lined storages; although the amount of water that can be stored will be small relative to the needs for irrigation in the dry season, so multiple storages will be needed and the area irrigated will necessarily be limited.
3. Capture of base flow in short, steep streams for a few months following the monsoon, using small temporary structures installed after quick-flow has slowed. Water could be captured in a series of small on-stream storages or carried (in pipes) to off-stream storages.

Option 1 is purely agronomic management to access the residual water following the monsoon and is discussed elsewhere in this report. Option 2 was discussed earlier.

With respect to option 3, local knowledge about the duration of baseflow will be the best guide to identifying potential streams to tap into. Permanent structures to hold flow back would be expensive and risk failure during periods of high flow. Small temporary structures (weirs) that are installed, or at least closed, during recession of the monsoon would have the potential to safely and economically retain the baseflow. The number of weirs needed would depend on both the rates of baseflow and the amount of water required for irrigation, but in no case is the weir seen as large water holding structure. It is a small structure to enable water to be withdrawn at relatively slow rates. This water could then be gravity fed direct to irrigated land if a ‘cascade’ of small weirs down a stream provided sufficient flow to not require a holding tank. If fewer weirs were installed, it may be necessary to feed water to a holding pond near the irrigated land to ensure sufficient water is available when irrigation is required. This approach may have the potential to capture more water than the multiple surface tanks in option 2, or to capture similar amounts of water with less landscape impact or lower cost.

Research is required to establish principles for the design and management of these approaches. But even without that, it is clear that no one approach will have universal application, and that an integrated approach will sometimes be needed.

Recommendation 7. Subsequent to a satisfactory outcome from 6, above, that research be undertaken to develop design principles (“thumb rules”) for the use of the three water harvesting approaches described above.

5.3.6 Springs drying up?

Shortage of drinking water from springs is a serious problem in some areas (see p16). Water harvesting has the potential to worsen the situation by transferring water from local stream or spring discharge to evapotranspiration, or to improve it by retaining ponded water in streams for longer and increasing infiltration (recharge) and local discharge. Only research can establish the actual outcome.

Some MoA staff expressed the view that changes in land use from trees/shrubs to pasture and especially to annual crops had led to a decline in drinking water from springs. I suspect that a change in rainfall amount and/or distribution is the real driving force. A shift from trees/shrubs to annual crops should lead to a decrease in transpiration and an increase in runoff and/or drainage, which both contribute to increased stream flow. Water balance calculations in this scoping study show that in areas with relatively lower rainfall, small reductions in autumn rainfall can dry up drainage. Farmers in Bhutan (as in India and Australia) spoke about changes in rainfall having led to a more risky environment in spring and autumn. This is consistent with predictions of climate change. Whether linked to climate change or not, small shifts in seasonal rainfall may account for big increases in risk, and further justifies investigation of the benefits of water harvesting.

Recommendation 8. A small study be undertaken to quantify any change in rainfall amount or seasonal distribution (Step 1), and combined with simple catchment water balance investigations (Step 2), to evaluate possible impacts on drainage and flow in local springs.

Bhutan should have the expertise to undertake this study with little or no external input.

Recommendation 9. That any future research on water harvesting estimate changes in the local water balance with particular emphasis on changes in local recharge and discharge.

5.3.7 Improved cropping/farming practices and systems

The traditional land use system makes use of compost based on leaf litter collected from oak or pine forest (sokshing) which is used as bedding for tethered cows, resulting in composted farm yard manure (FYM) which is often applied at quite high rates. This return of organic matter in dryland farming (kamzhing) is an important contributor to the remarkably low rates of erosion in what must be a fragile environment. Any farming systems research would need to be mindful of the success of this system and not recommend changes lightly. Nevertheless, the present system for arable agriculture leaves the ground bare of cover and in a tilled state at the time of year when runoff and erosion is most likely. See Recommendations 5 and 12 for suggested action.

The traditional land use system also includes areas referred to as ‘slash-and-burn or ‘shifting agriculture’ (tseri). These pejorative terms don’t acknowledge that tseri is often a rotational, low-intensity graze-and-grain system with inherent nutrient management practices. I suspect the problems associated with this land use may be overstated on occasions, although conversion of marginal land to ‘dryland’ may be a problem.

With respect to crop nutrition, the practice of sokshing ensures that P and K are unlikely to be major constraints in farming systems, but there is a low component of legumes overall, so the systems may be N-deficient. This could be manifest in reduced animal and/or crop production. Wider use of the traditional pulse intercrop with maize should be encouraged.

Fertiliser-N use is increasing but not well documented. It is likely that big productivity gains can be achieved with judicious use of N-fertiliser. Where rainfall is high and soils are porous, split applications of N or slow-release formulations of N will be beneficial.

With respect to plant varieties, rice breeding is limited to varieties for higher elevations, and there may be a case for selection for lower elevations for the Southern Zone. Maize is a major staple in Bhutan and modern open-pollinated varieties are used. With farmers saving seed, however, there is erosion of varietal integrity through outcrossing. The full benefits of improved nutrition, and irrigation enabled by water harvesting, will only be enjoyed with reliable genetic material, which may mean a move to hybrids. Also, to make best use of harvested water, shorter duration maize and mustard crops will be needed. Even without water harvesting, yields in present systems may be improved by quicker maturing varieties, at least in lower rainfall areas, and the opportunities for a third crop would be increased in higher-rainfall areas.

With respect to water, the first crop to be sown in the wet season is sown and often grown on marginal rainfall. Planting of the second crop is delayed by the need to cultivate the land, and the second crop may experience water deficits after flowering. Reduced tillage and crop residue retention should benefit crops in each of these situations by improving infiltration and reducing runoff and soil evaporation. Improved cultural practices should shorten the interval between the first and second crops because little or no tillage is needed. This should increase yields, even without irrigation using harvested water.

Recommendation 10.

(i) That consideration be given to improved documentation of N stocks and flows in farming systems, including rates of FYM and N-fertiliser use, to determine if N is likely to be a major constraint;

(ii) As fertiliser-N use increases, research (into types, rates, timing, split applications) and a focused extension program will be needed, especially in light of the high rainfall and porous soils which create a leaching potential.

The Council of RNR Research of Bhutan and Ministry of Agriculture appear to have the capability to undertake this high priority research and extension.

Recommendation 11. That existing maize and mustard plant improvement strategies be re-considered

This recommendation is made with a view to maintaining varietal integrity (maize) and making better use of quick-maturing Indian varieties (maize and mustard), with a particular focus on maturities that better match the opportunities created by the available water, including supplemental irrigation made possible through water harvesting. (Breeding may not be necessary, given the material available.)

Recommendation 12. That research quantify the changes in infiltration/ evaporation associated with reduced tillage and residue retention, and evaluate benefits in terms of yield for both crops in a year, and the potential to establish a third crop, with or without supplemental irrigation.

This work links to and extends Recommendation 2, and is a high priority for action.

5.3.8 Improved water use and water-use efficiency

Water harvesting will increase water-use in agriculture. The increase will be small relative to the total water balance, but it has the potential to make a large difference to agricultural production.

Water-use efficiency in rainfed agriculture is a function of management, not a parameter that is improved directly. Improvements in plant varieties and crop nutrition will lead to improved water-use efficiency. Comparisons of actual WUE with potential WUE are used in Australia to quantify the quality of management applied to a crop and to focus on areas of management that need improvement. In high rainfall areas where water is not limiting, radiation-use efficiency may be a more useful concept.

Where harvested water is used for irrigation, marginal water-use efficiency would be a useful measure, i.e. the increase in yield per unit of water applied. The use of supplemental irrigation to establish crops that grow primarily on residual water will result in very high 'apparent' marginal water-use efficiency.

5.3.9 Rice in the southern zone

The MoA would have liked this scoping study extended to include the southern zone, but time did not allow this. However, discussions were held where possible, and there has been an excellent analysis of the problem undertaken by Karma and Ghimiray[14], whose work warrants follow-up. They wisely recommend an 'integrated approach', and specifically cited investment in irrigation infrastructure, research and extension support for improved crop nutrition and general agronomic management and, where irrigation cannot be secured, rice breeding specifically for the southern zone (focus on drought resistance). Support for mechanisation is also recommended.

Rice yields in the southern zone are very low (<1t/ha), even with inputs of N (one report to me of around 30 kg/ha at planting and another 30 kg/ha 45 d later; although others report that fertiliser use is much lower). In the southern zone, rice is mostly not produced in 'wetland' as defined earlier in this report, but under 'rainfed, lowland' conditions (terraced and bunded). The area is >40% of the rice area in Bhutan but contributes only 29% to total production. Low yields are related to:

- Lack of irrigation, because the canal system in this region has become non-functional.

[14] Karma and Ghimiray M (2006). J Renewable Resources, Bhutan 2 (1):93-114.

- Crops are therefore more susceptible to periods of water deficit, especially during seedbed preparation through to transplanting early in the monsoon, and after flowering.

Karma and Ghimiray (2006) recommend breeding specifically for this environment. I agree, but in the meantime there may be benefits from locally adapting SRI[15] techniques for rice to address the problem of intermittent plant water deficits. Extensive work on SRI rice in nearby West Bengal has been undertaken by the Indian NGO PRADAN, and has now been adopted by more than 1,000 farmers. A visit to Purulia District would be advisable if work on SRI is considered. SRI rice receives only transient flooding and the plants are much better adapted to dry periods. A further benefit of SRI rice in areas which are irrigated is that it would greatly reduce irrigation water use because drainage on the porous soils would be reduced with shorter periods of flooding. Saved irrigation water could be used in higher value crops, such as vegetables. Successful preliminary trials on SRI were conducted in Trashigang District in 2006[16].

There may also be benefit in evaluating upland rice varieties available from the Upland Rice Research Institute, Hazaribag.

FYM use is low. Presumably N leaching is high with the porous soils (which are only temporarily flooded) and the very high rainfall. Loss of N in runoff may also be high if bunds are poorly maintained. Earlier research on the use of green manuring with Sesbania gave yields of 3t/ha, but farmers do not practice this, apparently because they cannot get the seed. Sesbania green manure would supply slow release N, but a similar result should be possible with 'prilled[17]' urea or split N applications. If leaching of N is high as suggested, there may be benefits from smaller applications of N provided more often.

Recommendation 13. That previous work on Sesbania green manure for rice in the Southern Zone be reviewed and if considered appropriate then steps be taken to encourage adoption, including improved availability of Sesbania seed.

This strategy should be compared with multiple split applications of N and the use of slow-release N products. This should be a high priority for action, and an area where very limited on-farm research on N rates and timing followed by extension could have a big impact.

Recommendation 14. That SRI production techniques for rice be evaluated in the non-irrigated area of the southern zone; and that upland rice varieties be evaluated.

In both cases, fertiliser N and P should be used as determined by experiments, which will mean some modification to SRI principles.

[15] System of Rice Intensification, an approach to rice production developed in Madagascar and adapted widely elsewhere.
[16] (Karma Lhendup, Sherubtse College, Royal University of Bhutan)
[17] Research on pelleted and coated urea has been undertaken by the International Fertiliser Development Corporation (IFDC) in Bangladesh.

5.3.10 Potential appropriate options for supplementary irrigation

Supplementary irrigation rather than full irrigation will be the best approach to using harvested water. This will maximise the use of stored soil water and result in high marginal irrigation water-use efficiency. Given the topography of Bhutan, low pressure gravity fed systems will be used. In the case of drip irrigation, which should make the best use of limited harvested water, pressure compensated drippers may have an advantage. Consideration should be given to sub surface drip irrigation that minimises water use and weed problems, and can be left in place between crops if minimal cultivation is used. The KISSS® system has the advantage of an impermeable layer beneath the drip tube to improve the spread of water and overcome problems associated with previous subsurface drip systems (http://www.kisss.net.au/).

6 Conclusions and recommendations

6.1 Synthesis of Recommended Priorities for Action

There is potential to ‘harvest’ water in Eastern Bhutan, although there are other measures that could also be taken to improve productivity which will also reduce land and water degradation. Water harvesting has the potential to reduce the riskiness of farming associated with variable rainfall, and is thus relevant to any discussion on climate change.

The integrated development of new tillage methods, crops with maturity better matched to climate, and access to limited (supplementary) irrigation, provide a very significant opportunity to increase productivity, reduce risk, and importantly, to improve soil conservation.

Research on soil management should be a high priority because of the benefits it will bring in terms of soil and water conservation, savings in labour, and potentially higher and more assured yields. However, nowhere in the world has this revolution occurred overnight. But where farmers have been involved in participatory research, practical problems have been solved quickly and adoption accelerated. There will need to be strong extension support, and perhaps policies to foster adoption, including selected input subsidies.

In this report, recommendations are made for (i) research for which Bhutan will require external support, (ii) research that is within current Bhutanese capability, (iii) extension and (iv) policy.

Of the research options that require external support, priority should be given to reviewing and if necessary implementing a wider national water flow/quality monitoring program and identifying and quantifying sediment sources, including necessary stream gauging. This will underpin any improvement to national policy and watershed protection programs.

Priority should also be given to developing the technology for zero/minimal tillage for erosion management and developing associated policies and programs to facilitate adoption.

Any policy to promote water harvesting will require research (with external support) to develop design principles, but this should be preceded by more thorough water balance modelling and an economic assessment to substantiate the expected benefits.

An important topic for consideration that is within the capability of the Bhutanese is a thorough, systemic assessment of nitrogen constraints in farming systems. There is evidence that N is a bigger constraint than is generally appreciated. Improved rice N-nutrition in the Southern Zone should prove especially beneficial.

Recommendation	Research Externally supported	Research No external support	Extension	Policy
1. Consider an “Environmental services scheme” to bring market forces to conservation				X
2. Implement a wider national water flow/quality monitoring program (links to recommendation 3)	?	X		
3. Identify and quantify sediment sources, including necessary stream gauging (links to recommendation 2, and may link to recommendations 5, 7, 9 and 12[18], if undertaken)	X			
4. Water User’s Associations to manage water reticulation, with increased support				X
5. Develop technology for zero/minimal tillage for erosion management and develop policies (including input subsidies) and programs to facilitate adoption (links to 12)	X			X
6. Desktop study of water balance and market potential to underpin applications for funding for water harvesting research		X		
7. Develop design principles for water harvesting (subject to outcome of 6, above)	X			
8. Investigate changes in rainfall amount and seasonal distribution, and their effect on discharge from springs (desktop)		X		
9. Any studies of water harvesting (under 7) should quantify change in recharge/discharge relationships, especially at local scale (springs)	X			
10. Include selection for quicker-maturing maize and mustard in plant improvement programs (to reduce risk and/or increase cropping frequency)		X		
11. Evaluate N constraint in dryland systems, including responses to inorganic N-fertiliser		X		

[18] Recommendations 5, 7, 9 and 12 could usefully be adopted as a ‘package’ of research.

12. 12 Study soil water responses to zero/minimum tillage, and the opportunity created to increase cropping intensity and/or reduce risks (see 5)	X			
13. In the Southern Zone, focus on N to improve rice yields, evaluate of earlier work on Sesbania		X	X	
14. Adapt and evaluate SRI and upland rice in drought prone areas of the Southern Zone (see also Recommendation 4 re infrastructure)		X		X

7 Appendices

7.1 Appendix 1. Bhutan Water Policy

1. Introduction

1.1 Bhutan has been consistently following a conservation-centered development policy. This policy has been inherited from the wisdom of our forefathers who knew that ensuring the integrity of forests, rivers and soil are vital to their survival in the mountainous environment. Their wisdom, which has been synthesized into our modern development philosophy, has been crucial in maintaining a good natural resource base. As the main outcome of this conservation policy, 72.5% of the country is under forest. This good vegetative cover on a mountainous topography with a fair spatial distribution of precipitation of 4000-5000 mm in the foothills, 700-2500 mm in the inner valleys and mid hills and 700-1000 mm in the high altitude regions has endowed the country with rich water resources. Fed by snow and rain, the country is drained by four major rivers and their numerous tributaries. Their average flow draining the country's area of 38,394 km2 is estimated at 2,325 m^3/s (Water Resources Management Plan, 2003), which is 73,000 million m3/annum with per capita availability of more that 100000 m^3. The mountainous topography, with altitudes varying from 100 meters to over 7,500 meters above sea level, drained by these rivers and their tributaries has given the country a high potential for hydropower development.

1.2 However, Bhutan cannot afford to be complacent. The country is confronted with localized and seasonal water shortages for drinking and agricultural purposes. Only 78% of the country's population has access to safe drinking water and about 12.5% of the arable land is irrigated. The high per capita availability of water at the national level is in stark contrast to local water scarcity, which has become a serious impediment to development). This problem of access to water is caused by the settlements being on the slopes while the major rivers flow at the valley bottoms. However, the country's annual precipitation gives some prospect to deal with the local water scarcity. Harvesting a small fraction of this huge quantity of rainwater has the potential to solve the local water scarcity problems and lead to judicious use of available water.

1.3 There is increase in fluctuation between lean season and monsoon season flows leading to sub-optimal utilization of generating capacity of hydropower plants. The increasing sediment load in rivers is decreasing the expected output and economic life of hydropower plants. The uneven distribution of precipitation over the fragile mountainous environment makes the country highly vulnerable to landslides, floods, droughts and impacts of climate change.

1.4 Pressure on water resources is mounting due to competing demands from different users. In the past, water was mainly used for domestic and agricultural purposes. Even the demand for domestic water is increasing due to changing lifestyles caused by rapid socio-economic development. Similarly, the water demand by agriculture is expected to increase due to production intensification to keep pace with food demands of a growing population. New demands from other sub-sectors such as hydropower and industries are emerging and must be accommodated. Rapid urbanisation is taking place, which has serious impacts both on water demand in terms of quantity required and the associated pollution that impairs quality.

1.5 Effective watershed management is imperative for water resources conservation and sustainable utilization. However, due to the rapid pace of socio-economic development, there is increased pressure on the watersheds. Although harvesting of forest produce is based on sustainable management plans, increasing demand for timber, firewood and non-timber forest produce is starting to have negative impacts on watersheds. Further, forestland encroachment and forest fires have become challenges for watershed conservation. Therefore, watershed management as the reservoir of water and other related resources is a challenge that must be addressed collectively in the interest of all resource users.

1.6 At a growth rate of 1.3% per annum, our population will double in the next fifty years. About half the population are projected to live in urban centres. Such a concentration of population poses a serious challenge to delivery of services and waste management of a burgeoning population. Given the limited arable and plain land, such concentration will undermine sustainable management of land and water resources, compromising the low carrying capacity of the fragile mountainous ecosystem.

1.7 Climate change has serious impacts on Bhutan. Glacial Lake Outburst Floods (GLOF) are increasingly becoming threats due to melting of glaciers triggered by climate change. GLOFs have serious impacts on life, properties and future infrastructure development in the country. Another major impact of climate change will be in reducing the natural flow regulating capacity of the glaciers for our rivers with serious consequences on our water resources. Therefore, since Bhutan is affected by phenomenon on which we have no control, we must participate in international forums on climate change to negotiate on mitigation measures for our important resources.

1.8 The existing water user institutions have weak functional linkages at policy, planning and programming levels. The different sub-sectors have been performing their respective responsibilities independent of each other. This has resulted in fragmented data, duplication of efforts and poor resource management system. It has sacrificed the synergy of integration. For instance, the drinking water program is looked after by two ministries: urban water supply is under Ministry of Works and Human Settlements and rural water supply is with the Ministry of Health. Similarly, while the Ministry of Agriculture handles irrigation and land-use, hydropower development and hydro-meteorological data collection and GLOF are looked after by the Ministry of Trade & Industry. Such an institutional set up has, above all, resulted to the absence of a national policy on water which is an important national resource and created sub-sector based institutions leaving rooms for potential conflicts among them.

The Royal Government established, in August 2001, a multi-stakeholder body called Bhutan water Partnership, comprising of relevant agencies in the water resources sector, as an interim measure, to undertake the following activities:

- to co-ordinate and formulate a broad national water policy along with the required legislation
- to co-ordinate and prepare the Bhutan Water Vision for the next twenty five years

- to co-ordinate and prepare water action plans for integrated water resources management on plan period time horizon
- to co-ordinate and prepare the institutional linkage mechanism within and beyond the water resources sector

To review and co-ordinate the preparation of a comprehensive HRD plan in the water resources sector:

- to act as the national counterpart to consultants involved in policy formulation and management of water resources
- to act as a policy advisory committee to the government on water resources protection, development and management
- to act as the focal body to the South Asian Network of the Global Water Partnership
- to monitor and evaluate the programs on water resources implemented by the different sub-sectors.

1.9 There is no law on water in its own merit. However, some provisions related to water issues exist in some existing Acts such as the Land Act, 1979, Forest and Nature Conservation Act, 1995, Environment Assessment Act, 2000, Bhutan Electricity Act, 2001 and Water and Sanitation Rules (framed in pursuance of the Municipal Act 1999). These provisions are not comprehensive and are sometimes contradictory, inconsistent and conflicting with each other. Besides, the people also practice customary law and norms, which differ from village to village. Therefore there is a need for the enactment of a comprehensive law on water.

1.10 On the international front, Bhutan is signatory to the United Nations Convention on the Law of the Sea, UN Framework Convention on Climate Change, Kyoto Protocol to the UN Framework Convention on Climate Change; Convention on Biological Diversity,; Cartagena Protocol on Biosafety to the Convention on Biological Diversity; Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITIES); Basel Convention on the control of Transboundary Movements of Hazardous Wastes and their Disposal; UNESCO World Heritage Convention; International Plant Protection Convention (Adherence); Statute of the Centre for Science and Technology of the Movement of Non-Aligned Countries and other Developing Countries; Statutes of the International Centre for Genetic Engineering and Biotechnology.

2. Water Vision for Bhutan

Vision Statement

Water is the most important natural, economic and life-sustaining resource and we must ensure that it is available in abundance to meet the increasing demands. Present and future generations will have assured access to adequate, safe and affordable water to maintain and enhance the quality of their lives and the integrity of natural ecosystems.

2.1 Nature, water and human life are interdependent and inseparable and must coexist in harmony and balance.

2.2 To achieve this vision, water must be used and managed sustainably, efficiently and equitably while recognizing and preserving the environmental, social, cultural and economic value and uses of water.

2.3 All water users, planners and decision-makers shall be adequately informed, educated and encouraged to value and protect water in all its forms and uses.

2.4 Realizing this vision requires the involvement of all people in Bhutan working in a continuous partnership within an enabling policy, legal and institutional framework.

3. Need for Water Policy

3.1 Water is a precious natural resource, a basic human need for survival. The development and management of water resources must be therefore guided by national conservation and sustainable development policies.

3.2 The Royal Government has taken the decision that sustainable agriculture development, harnessing hydropower potential and industrial development shall be the main avenues of socio-economic development. Water is one of the main resources required in fulfilling this important national objective of socio-economic development. Therefore, the need for a water policy to guide the sector in the best interest of the nation cannot be over-emphasized.

3.3 Water is finite. Socio-economic development inevitably leads to increasing demand of water for diverse purposes: domestic, agricultural, hydropower, industrial, recreational etc. Water is a crucial element in all these development areas. Therefore, conservation, development, utilization and management of this important resource have to be guided by national goals.

3.4 The need for an integrated approach is crucial for effective management of water resources for fulfilling our diverse national objectives. An enabling environment shall be created for active participation of all stakeholders and for an integrated water resources management.

3.5 Floods including GLOF affect vast areas resulting in loss of lives and properties. It is essential to develop a national adaptation strategy for climate change, including a national flood management and mitigation strategy.

3.6 A common framework for water resources assessment is crucial for informed decision-making. The inventory of water resources both in terms of quality and quantity needs to be developed.

3.7 There is a need for coordinated efforts on all water resources development in the country. It is also pertinent that an institution be created to ensure an integrated approach in the management of water resources and its sustainable utilization.

4. Policy Statements

4.1 The Bhutan Water Policy is a reflection of the Royal government’s commitment on the conservation, development and management of the country’s water resources. It recognizes that water is a precious natural resource and a heritage important to all aspects of social, economic and environmental wellbeing. Therefore, water resources must be carefully conserved and managed in order to promote national development without compromising the integrity of the natural ecosystem.

4.2 The policy adopts an integrated approach, which recognizes natural linkages. Emphasis is placed on water resources management within river basins and aquifers, including both upstream and downstream water users. Surface and ground water must be seen as two forms of the same resource, often with close linkages. Water quality and quantity are important and interlinked. Water resources must be planned and managed in a coordinated manner.

4.3 Water is crucial for development since it is the resource that guarantees basic wellbeing for all. Water programs must address balanced development and grant equitable access to this basic resource to meet the basic condition for happiness thereby contributing to the national goal of Gross National Happiness (GNH)

4.3 Water support human sustenance and therefore has direct linkage to poverty. Recognizing this strong linkage, water related programs shall address poverty and offer people their right to respectable livelihoods.

4.4 The policy shall cover all forms of water resources including snow, glacier, rivers, lakes, streams, springs, wetlands, rainwater, soil moisture and groundwater.

4.5 The Water Policy views water resources from a broad, multi-sectoral perspective while recognising the responsibility of the sub-sectors to play their part in meeting the policy objectives. The policy principles are thematically grouped as follows:

- water user interests and priorities
- principles for water resource development and management
- institutional development for water resources management
- international waters.

5. Water User Interests and Priorities

5.1 Allocation of Water

5.1.1 When water resources are not sufficient either in quantity or quality to meet every legitimate demand, water for drinking and sanitation for human survival shall be the primary priority. Water for irrigation, hydropower generation, industrial use, recreation, and other uses shall be considered based on national and local priorities. Water legislation and management practices should allow for flexibility for adopting practical local solutions.

5.1.2 Water is indispensable for nature conservation and this shall be a guiding element in water allocation decisions.

5.2 Water for Drinking and Sanitation

5.2.1 Water is essential for human survival and health. Therefore every individual has the right to safe, affordable and sufficient quantity of water for personal consumption and sanitation.

5.2.2 The goal of the Royal Government shall be to provide universal access to safe drinking water and sanitation. While doing so, national standards for water quality shall be developed and followed.

5.2.3 There are reports of drying up of streams and springs as sources for drinking water. Consistent efforts shall be made to protect and conserve drinking water sources and the best available water sources shall be allocated for drinking purposes. In addition, alternative sources like groundwater and rainwater harvesting shall be explored in areas with water shortage.

5.3 Water for Food Production

5.3.1 Sustainable agriculture development is an important component of socio-economic development. It is the source of livelihood for 69% of the population. Adequate water allocation to this sector is indispensable for achieving overall national food security. Therefore, water allocation to the sector must be compatible with this national objective. A certain provision of water for consumption by domestic animals has to be made.

5.3.2 Agriculture consumes the highest percentage of water. With population growth and increasing competition for water from other sub-sectors, it is imperative that higher efficiency ("more crop per drop") has to be achieved through adaptive and applied research. In order to address seasonal and local water shortages, other sources of water like groundwater and rainwater harvesting shall be promoted wherever feasible.

5.3.3 As agriculture production has the potential to pollute water resources through use of fertilizers and pesticides, efforts will be made to manage soil and pests without using excessive chemicals to avoid pollution of water resources from non-point agriculture sources.

5.3.4 The role of the rivers as an aquatic habitat and as a source of food shall be recognised.

5.4 Water for Hydropower Development

5.4.1 The mountainous topography of the country, with varying altitudes and swift flowing rivers in deep valleys carrying sufficient run-offs originating in fairly un-disturbed watersheds, provides the advantage for hydropower development.

5.4.2 Hydropower shall continue to be the backbone of the Bhutanese economy providing adequate energy for growth.

5.4.3 Hydropower development as a non-consumptive use of water, its significance as a renewable, non-polluting and clean form of energy and its potential for earning revenues from export shall be recognized. The sub-sector's tremendous potential for socio-economic development of the Kingdom shall be harnessed in a sustainable manner.

5.4.4 Hydropower development and transmission of energy have linkages with upstream, downstream and en-route water and land-users and therefore there is a need for cooperation and coordination in working out tradeoffs. These shall be approached through consultation and all users shall consider tradeoff, keeping in view the overall national interest.

5.5 Water for Industrial Use

5.5.1 The need for water by industries shall be recognised. Its rational and efficient use with proper disposal of wastewater is mandatory. The prospect of mountain spring water as an environmentally clean product shall be encouraged.

5.5.2 Development of tourism and recreational potential on Bhutan's watercourses will create additional opportunities and shall be promoted in a sustainable and environment-friendly manner. The potential of hot springs, which have medicinal, cultural as well as recreational value, shall be promoted.

5.6 Water Use and Conflicting Users' Interests

5.6.1 Competing water uses which result in conflicting water users' interests shall be solved through legal instruments. Legislation related to water that exist in various Acts are not comprehensive, and does not address the current and future water issues sufficiently. There is therefore a pressing need to enact a comprehensive legislation on water, which shall regulate water use in a sustainable way, resolve water-related conflicts, and ensure necessary conservation of water resources. The Water Act shall recognize and respect customary rights that are based on justice, equity and good faith.

5.6.2 Water in Bhutan shall be a common good. The State shall have the right to regulate the use of water resources and intervene in cases of conflicts. However, water management shall be broad-based with the involvement of all stakeholders through a consultative process. The use of water shall be open to all legitimate users under the provisions of the Water Act.

5.6.3 A comprehensive water legislation and regulations along with elaborate water abstraction procedures shall be developed. Licensing of activities that abstract water for commercial use shall be made mandatory. The licence shall specify the quantity, time frame, and quality of abstractions and discharge of effluents. The legislation shall also lay down provisions for a systematic registration of all forms of water uses, for the purposes of national integrated management plan and other uses.

5.6.4 The Water Act shall take into account international legal norms and conventions that Bhutan is signatory to.

6. Principles of Water Resources Development and Management

Water resources development, management and conservation must be done in an integrated manner for long-term sustainability. Sustained flow of good quality water depends on the integrity of the watershed. Water is a crosscutting resource because of its universal utility. It is a social and an economic good which transcends all social barriers. These characteristics of water shall form the basis to integrate our efforts in water resources development, management and conservation.

6.1. Water Resources Development

6.1.1 Sustainability of water resources means to integrate conservation, development and management on scientific basis, to maintain the safe yield of surface water sources, to prevent water pollution, to reduce the risks of flood and landslide damage and to promote the active participation of all stakeholders. Sustainable technical systems shall involve investigations, sound and affordable designs followed by construction of high quality infrastructure and their effective maintenance.

6.1.2 The use of appropriate technologies backed up by good management practices shall be promoted for saving water in households, agriculture and industrial uses.

6.1.3 Water resources development shall be carried out in an environmentally sustainable, economically feasible and socially acceptable manner.

6.1.4 Water resources development shall be based on applied research results and development activities relevant for Bhutan. These shall include programs and activities on source protection, groundwater abstraction, rainwater harvesting, recycling and reuse and innovative management practices. Integrated and coordinated development of surface and groundwater and their conjunctive use shall be promoted in feasible areas.

6.1.5 Water resources conservation, development and management programs are capital-intensive. A prudent fiscal policy to develop the sector shall be important for its growth. Investment from the private sector shall be encouraged. Preference shall be given to cost-effective, multi-purpose and multi-users projects.

6.2 Water Resources Management

6.2.1 Water resources management shall respect the integrity of rivers, surface and groundwater. As land-use has direct impact on water cycle, it is crucial that land-use planning take place at the river basin level. The upstream-downstream relationship has impact on the management of water resources. Therefore, water resource management in Bhutan shall be based on natural river basins. Conflicting user interests shall be resolved in a river basin context as a norm.

6.2.2 The main river basins shall form natural units of a national water management system. Appropriate institutional structures for water resources management at the basin level shall be developed.

6.2.3 Consistent water demand management shall complement the optimal development of water supply. Demand management shall include water-saving technologies, regulatory measures and enhancing public awareness. Pricing policies are effective tools for managing water demand, and this shall be an integral part of the water policy.

6.2.4 Water resources management shall be carried out in an integrated manner. Many water management problems, leading to crises of quantity and quality are associated with lack of integration, top-down management and disregard of upstream-downstream relationship. The important elements of an integrated water management shall include:

- Water flow circulation within the river basin, between the basins and the surroundings shall always be taken into consideration
- Land-use planning shall take place within the framework of the river basin
- It shall recognize the transport of matter, including polluting substances, that occurs between soil, air and water
- It shall recognize that usable water is always a function of both quality and quantity, and the two are strongly inter-connected
- Water supply and wastewater management shall be integrated at all administrative levels
- Rivers, lakes and other wetlands shall be sustained as biotopes for aquatic life
- All legitimate water users shall be equally respected, and have a voice in decision-making
- Central and local water management shall be consistent and interlinked
- Integrated water management shall include monitoring, data collection, analysis and access
- Integrated water resources management shall also include management measures related to monitoring, early warning and mitigation of floods, landslides, damage to agricultural land and Glacial Lake Outburst Floods.

6.2.5 Participation of both genders in water resources management decisions shall be encouraged. Therefore, water related programs shall take into consideration the important role of women and men with respect to equal sharing of burden and benefits. Both men and women shall be involved in planning, development and management of water resources programs. A concerted effort to sensitize the importance of gender equity in water resources programs shall be implemented.

6.3 Value of Water

6.3.1 Water has an economic and a social value. Demand management techniques shall be introduced in order to achieve equitable sharing when there are competing water users. Economic instruments are efficient in modifying demand, and this shall be applied with care. Sustainable management of water as a resource is only possible when its full cost is acknowledged during planning and development of water projects. Cost recovery schemes shall include economic and environmental costs. Tariff structures shall therefore aim at sustainability of providing water.

6.3.2 Economic tools for water demand management will be introduced. Royalties or other means of rent/levy on water shall be considered for commercial water uses. Economic tools for promoting preferred or environmentally beneficial practices shall be promoted.

6.3.3 Use of water resources that causes pollution shall be regulated. The cost of pollution mitigation shall be based on the "polluter pays principle."

6.3.4 The principle of cost sharing on water resource development and management shall be further strengthened to inculcate a sense of participation and ownership for sustainability.

6.4 Water Resources Protection

6.4.1 All forms of water resources shall be protected. Pollution impairs water quality, and hence reduces the water resource base. Pollution of water resources from urban development, agriculture, construction industry shall be controlled and the policy shall promote use of clean and appropriate technology. Watersheds' essential role as a sustainable source of water shall be protected.

6.4.2 Watersheds play an important role in regulating and maintaining water flow. The Royal Government of Bhutan shall ensure that adequate funds and resources are ploughed back for watershed protection and management. The plough back mechanism shall be used as an important tool for water resources management and development.

6.4.3 It is particularly important to protect the watershed providing drinking water. Surface water sources that are used for water supply shall be protected. The quality of groundwater shall be monitored in view of the potential future role of groundwater as a source of water, and co-ordinated with the general surface water quality monitoring.

6.4.4 Water quality will be maintained by creating awareness on water pollution Environmental impact assessments shall give special considerations to impacts on water and aquatic life. Introduction of clean technologies for industrial production shall be promoted.

6.5 Flood Control and Management

6.5.1 Integrated and coordinated approach in flood control and management is essential. Action plans and programmes shall be developed for monitoring, early warning of flood hazards and disaster management. Particular attention shall be given to threats from floods, including glacial lake outburst floods.

6.5.2 Disaster management plan including forecasting, prevention, evacuation and mitigating measures shall be developed for flood-prone basins. Sound watershed management through extensive soil conservation, watershed area treatment, conservation of forests shall be promoted to reduce the incidence and intensity of floods. Flood forecasting and warning system shall be established along with regulations for human settlements and construction of physical flood protection works to minimize loss of life and properties due to floods.

6.5.3 Infrastructure for flood protection and damage prevention shall be strengthened. Flood zoning shall be carried out as an important disaster prevention measure. Measures to reduce threats from glacial lake outburst floods shall be taken up.

6.5.4 Unmanaged water has great potential for destruction and pose huge risks to assets, lives, economy and the environment. It is important to know the destructive capacity of water and take appropriate safety and management measures while dealing with water and related activities. This is the responsibility of every individual and organization that use and deal with water at individual or collective levels.

7. Institutional Development for Water Resources Management:

7.1 Institutional Set Up

7.1.1 The National Environment Commission shall ensure effective co-ordination of water resources management at the national level. The mandate shall include:

- Planning of water resources at national level
- Formulation of water policy and required legislation
- Monitoring and evaluation
- Setting water quality standards and guidelines
- International water co-operation
- Licensing and regulating activities
- Report to the Government/National assembly.

7.1.2 Further, in collaboration with relevant sectors, the NEC shall coordinate:

- Research, development planning and support
- Capacity building and technical backstopping
- Coordination of emergency preparedness
- Data collection and distribution
- Flood and disaster management related to water resources.

7.1.3 The line ministries, departments, divisions and other organisations shall implement their respective functional responsibilities within the policy and legal framework. For ensuring effectiveness of the institutions in the water sector, better coordination and linkage mechanisms among them shall be promoted.

7.1.4 The Royal Government may form advisory bodies, from time to time, consisting of representatives from civil society and water users organizations, to provide advice to the government on water-related issues.

7.1.5 Operational management of water resources shall be carried out at the regional and local level with active participation of stakeholders. The practical management of water resources shall be implemented at appropriate levels. The line agencies shall ensure their linkage with local organisations to ensure effective implementation of activities on water with active participation of the beneficiaries. In line with the decentralisation policy, the Dzongkhag Yargay Tshogdu and Geog Yargay Tshogchung at the Dzongkhag and geog levels respectively shall play important roles in planning, implementation, operation and management of all water programs. The role of private sector and non-governmental organisations shall be encouraged in supplementing the services on water provided by the public sector. Private sector participation shall be guided by public authorities, which shall set the requirements for minimum service standards.

7.2 Responsibility for the Management of the Water Resources

7.2.1 The State shall act as the trustee of water resources and shall be responsible for overall regulation and management. Since water is a valuable resource that should be protected in the public interest, the State has an obligation to ensure a just, equitable and sustainable allocation among all legitimate water users including rationing during scarcity.

7.3 Management of Information System

7.3.1 A prime requisite for efficient water resource conservation, development, management and planning is a well-developed information management system. A standardized national information management system with network of data banks and databases shall be established. The establishment's main function will be designing information collection network and data collection with integration and strengthening of the existing central and dzongkhag level agencies. It shall work towards improving the quality of data and its processing. Information and Communication Technology (ICT) shall be adopted as an effective tool for this purpose. It shall facilitate free exchange of data among the various partner organizations for dissemination of information.

7.4 Human Resources Development

7.4.1 For efficient management and development of water resources, sufficient human resources, their skills and knowledge are important prerequisites. Therefore a prospective plan for training of planners, managers, implementers and the users shall form an integral part of the institutional capacity building measures. In this regard, priority trainings shall be imparted on information systems, cross-sectoral and integrated planning, multi-purpose project planning and formulation, project management, conservation, watershed hydrology, operations and maintenance of physical infrastructures related to water resources management and development.

7.4.2 Awareness campaigns and sensitizing all users on the importance of water are important aspects that need special attention. In this regard, there is need for training of sociologists and institutional experts to encourage efficient management and development of water resources.

7.4.3 Efforts should also be made to highlight the importance of water resources in the curriculum of all relevant educational institutions.

7.5 Applied Research in Water Resources Development & Management

7.5.1 For effective and economic management of resources and also to keep with the dynamics of change and development, constant efforts shall be made in applied research on water conservation, management and development.

7.5.2 The following areas need special attention

1. Hydrometeorology
2. Assessment of the National Water Resources
3. Surface water source and watershed protection
4. Ground water hydrology and recharge
5. Water harvesting
6. Water balance studies
7. Crop water requirements and cropping systems
8. Soil erosion and bio-engineering
9. Flood control and mitigation
10. Erosion of the watercourse and sedimentation of reservoirs

11. Safety of hydraulic structures
12. Recycling and re-use
13. Best practices
14. Economic and financial planning
15. Wastewater
16. Water pollution and prevention.

7.2 Appendix 2. Average monthly rainfall by District

(20-year data, Ministry of Agriculture)

District (Dzongkhag)	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Samtse	29	40	101	218	441	692	883	802	582	315	66	16	4186
Sarpang	22	36	80	207	407	827	1272	1178	730	409	105	75	5348
Thimphu	12	11	22	36	53	130	167	157	87	34	1	3	713
Trashigang	15	30	47	105	125	209	299	263	174	98	35	12	1413
Trashi Yangtse	11	27	51	105	134	172	230	223	177	91	15	7	1244
Trongsa	17	28	51	93	144	193	246	214	154	84	15	6	1245
Tsirang	12	13	52	83	133	328	478	378	182	127	12	6	1803
Wangdi	12	14	22	52	60	142	169	153	101	63	13	5	804
Zhemgang	18	24	41	76	125	251	359	232	191	91	11	10	1429
Bumthang	7	10	28	54	83	117	139	132	97	67	11	5	751
Chukha	26	45	78	126	159	247	312	266	180	107	25	7	1579
Dagana	0	0	10	204	98	179	277	78	332	75	7	20	1280
Gasa	33	36	81	121	222	309	471	412	250	157	64	22	2176
Haa	11	17	33	65	68	147	205	199	134	97	22	8	1007
Lhuentse	11	17	32	69	120	123	198	164	115	70	17	5	939
Mongar	7	12	36	71	89	133	217	178	81	71	16	3	915
Punakha	21	30	22	51	76	172	213	188	108	65	11	3	961
Paro	12	12	23	29	49	100	143	129	100	73	18	8	694
Pemagatshel	16	41	120	155	193	326	510	336	175	161	44	16	2094
S/Jongkhar	17	53	111	309	491	891	881	603	431	159	37	8	3991

7.3 Appendix 3. Agroecological zones of Bhutan

Agro-ecological Zones	ALTITUDE RANGE (M)	Annual rainfall (mm)	Max. annual temperature (0C)	Min. annual temperature(0C)	Annual mean temperature (0C)
Alpine	3,600-4,600	< 650	12	-0.9	5.5
Cool Temperate	2,600-3,600	650-850	22.3	0.1	9.9
Warm Temperate	1,800-2,600	650-850	26.3	0.1	12.5
Dry Subtropical	1,200-1,800	1,200-1,800	28.7	3	17.2
Humid Subtropical	600-1,200	1,200-2,500	33	4.6	19.5
Wet Subtropical	150-600	2,500-5,500	34.6	11.6	23.6

Source: Gyamthso, P. 1996. Assessment of the condition and potential of high altitude rangelands of Bhutan. PhD Thesis submitted to Swiss Federal Institute of Technology, Zurich.