



REPORT SNO 3943-1998

Mangdechu Hydroelectric Project

Environmental and Socio-economic Impact
Assessment Study:

**Water Quality and Sanitation,
Aquatic Flora and Fauna**



The Dzong (building to the left) in Trongsa and the valley where Mangdechu River runs in the bottom

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Abstract

A hydropower regulation scheme is under planning in the river Mangdechu in Trongsa, Central Bhutan. This study comprises the impact assessment of the "Water Quality and Sanitation" and "Aquatic Flora and Fauna" in the Environmental Impact Assessment Study for the regulation project. Mangdechu has soft water with slightly alkaline reaction. Periodically, the river carries large amounts of suspended solids mainly in the rainy season. Periphyton constitutes the most important primary producer group in the river. The bottom fauna was richer in the reservoir area than in the tailrace area. The river stretch downstream of the dam and down to the confluence with the tributary, Chendebjichu, will be seriously impacted by the water diversion. Although the water use interests are small for the stretch, a minimum release over the dam of 1.5-3 m³/s seems necessary to take care of river ecology, water supply for wild life and pastured cows. If the power station will be utilized for maximum peaking production during the dry period, the river downstream of the tailrace entrance will be seriously impacted for many kilometres if there will be sudden increases/decreases of water flow. An adequate operation strategy to prevent too rapid changes in the water flow must be developed. The population will increase in the district. Labour camps must be equipped with adequate drinking water supply and sanitary devices. The drinking water supply and the sanitation system of Trongsa town must be rehabilitated. It should be developed sedimentation basins, and if possible, infiltration devices for tunnel water. The spoil deposits should be well drained to prevent runoff of erosion material to the river.

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PREFACE

This document reports the items “Water Quality and Sanitation” and “Aquatic Flora and Fauna” of the Environmental and Socio-Economic Impact Assessment (EIA) in the Feasibility Study of Mangdechu Hydroelectric Project, Bhutan. Division of Power (DOP), Ministry of Trade and Industry, Royal Government of Bhutan, is the client for the Study. The overall EIA is co-ordinated by Statkraft Engineering (SE).

The field work was carried out in April, June, and September/October 1998. The collection of water samples, samples of aquatic flora and fauna (other than fish) were performed by Dag Berge, Norwegian Institute for Water Research (NIVA), and Pasupati Sharma (DOP), Sediment Lab Unit. During the wet season water samples were kindly collected by Bernt Høygaard, Norconsult, the Main Consultant (MC).

The collection of information concerning water supply and sanitation is performed by Dag Berge, Anja Skiple (NIVA), and Hans Olav Ibrek (SE).

The suspended sediment samples were analysed at the Sediment Lab Unit at DOP. The bacteriological analyses were carried out at the laboratory at Trongsa Hospital. The chemical analyses are performed at NIVA. The bottom dwelling animal material is identified and treated by Torleif Bækken, NIVA. The periphyton material is identified and treated by Randi Romstad, NIVA.

The report is compiled by Dag Berge, Torleif Bækken, and Anja Skiple.

Trongsa/Thimphu/Oslo, October 1998

Dag Berge

Table of Contents

| | | |
|-------|---|----|
| 1 | Executive summary | 9 |
| 1.1 | Water quality | 9 |
| 1.2 | Water supply and sanitation | 9 |
| 1.3 | Aquatic Flora and Fauna | 10 |
| 1.4 | Impacts on water quality and aquatic life..... | 10 |
| 1.5 | Impacts on water supply and sanitation..... | 10 |
| 1.6 | Mitigation measures | 11 |
| 2 | Introduction | 12 |
| 2.1 | Background | 12 |
| 2.2 | Short description of the river and the hydropower development | 12 |
| 2.3 | Aim of the Study | 13 |
| 3 | Review of existing literature | 14 |
| 4 | Assessing water user interest in Mangdechu River | 15 |
| 4.1 | Introduction | 15 |
| 4.2 | Assessment of the existing water use interests in Mangdechu | 15 |
| 5 | Field work: Water Quality in Mangdechu River..... | 16 |
| 5.1 | Sampling stations | 16 |
| 5.2 | Water Quality Parameters and analysis..... | 16 |
| 6 | Results: Water Quality Study..... | 17 |
| 6.1 | In-Situ Measurements..... | 17 |
| 6.2 | General water quality parameters..... | 17 |
| 6.3 | Suspended solids | 18 |
| 6.4 | Nutrients | 20 |
| 6.5 | Major cations..... | 20 |
| 6.6 | Major anions..... | 21 |
| 6.7 | Bacterial analysis..... | 22 |
| 6.8 | Impacts on Water Quality..... | 22 |
| 6.9 | Mitigation measures | 23 |
| 7 | Water Supply and Sanitation..... | 24 |
| 7.1 | Introduction | 24 |
| 7.2 | Rural areas..... | 25 |
| 7.2.1 | Rural water supply: present situation | 25 |
| 7.2.2 | Rural sanitation: present situation | 25 |
| 7.2.3 | Impacts of the project..... | 25 |
| 7.2.4 | Mitigation measures | 26 |
| 7.2.5 | Monitoring..... | 26 |
| 7.2.6 | Costs of mitigation measures..... | 26 |
| 7.3 | Trongsa town (urban area) | 26 |
| 7.3.1 | Urban water supply: present situation | 26 |
| 7.3.2 | Urban sanitation: present situation | 27 |
| 7.3.3 | Impacts | 27 |
| 7.3.4 | Mitigation measures | 27 |
| 7.3.5 | Costs | 28 |
| 7.4 | Project camps | 28 |
| 7.4.1 | Temporary labour camps..... | 28 |
| 7.4.2 | Permanent camps..... | 29 |
| 7.4.3 | Mitigation measures at the camps | 29 |
| 7.4.4 | Costs | 29 |
| 7.4.5 | Monitoring plan..... | 29 |
| 8 | Aquatic Flora and Fauna | 30 |

| | | |
|--------|--|----|
| 8.1 | Introduction | 30 |
| 8.2 | Review of existing literature | 30 |
| 8.3 | Field work in Mangdechu 1998..... | 30 |
| 8.3.1 | Sampling stations | 30 |
| 8.3.2 | Description of the water habitats:..... | 30 |
| 8.3.3 | Sampling of biological material | 30 |
| 8.4 | Results: Aquatic macrophytes | 31 |
| 8.5 | Results: Phytoplankton..... | 31 |
| 8.6 | Results: Periphyton..... | 31 |
| 8.6.1 | Degree of Coverage..... | 31 |
| 8.6.2 | Species composition | 32 |
| 8.7 | Results: Bottom dwelling animals..... | 33 |
| 8.8 | Impacts on Aquatic Life | 35 |
| 9 | Mitigating Measures..... | 37 |
| 9.1 | Short description of the different measures..... | 37 |
| 9.2 | Cost of mitigating measures | 38 |
| 10 | Monitoring plan..... | 40 |
| 10.1 | Laboratories..... | 40 |
| 10.2 | Construction period | 40 |
| 10.2.1 | Mangdechu | 40 |
| 10.2.2 | Tunnel water | 40 |
| 10.2.3 | Primary recipient for spoil deposits..... | 40 |
| 10.2.4 | Areas for fuel, chemical, and machine storage/repair | 41 |
| 10.2.5 | Labour camp drinking water supply..... | 41 |
| 10.2.6 | Labour camp sanitary discharges | 41 |
| 10.2.7 | Cost estimate for construction period monitoring | 41 |
| 10.3 | Monitoring Plan for the Operation Period..... | 41 |
| 10.3.1 | Mangdechu River | 41 |
| 10.3.2 | Labour and operation staff camps | 42 |
| 10.3.3 | Cost of post construction monitoring programme..... | 42 |
| 11 | Consultations and literature..... | 43 |
| 11.1 | Consultations..... | 43 |
| 11.2 | Literature | 43 |
| 12 | Appendix – Primary data referred to in text..... | 44 |

List over Figures

| | |
|--|----|
| Figure 2.1 Mangdechu river and the location of the project area..... | 12 |
| Figure 2.2 Monthly mean water flow in Mangdechu River at the damsite..... | 13 |
| Figure 6.1 Mangdechu 1998. Some general water quality parameters. The April values represent a dry period, while the June values represent the rainy season. | 18 |
| Figure 6.2 Suspended sediments in Mangdechu at Jeezam Bridge (the road crossing just upstream Trongsa) 1996 and 1997. The upper panel shows monthly transport values, the lower panel shows monthly mean concentrations. Data from DOP's monitoring, month without column = lack of data. | 19 |
| Figure 6.3 Concentration of suspended solids in Mangdechu River observed during the water quality sampling. Left panel shows the difference between wet and dry season, while the right panel shows the inorganic and organic fraction of the suspended solids in the river water in June 30-98 (wet season). | 19 |
| Figure 6.4 Mangdechu 1998. Observed concentrations of the plant nutrients phosphorus and nitrogen. The April values represent the dry season, while the June values represent the rainy season. | 20 |
| Figure 6.5 Main cations in Mangdechu during the water quality sampling (April data represents dry season, while June data represent wet season..... | 21 |
| Figure 6.6 Main anions in Mangdechu during the water quality sampling (April data represent the dry season, while June data represent the wet season..... | 22 |
| Figure 8.1 Approximate bottom coverage of the periphyton elements cited. Visually judged in the field..... | 32 |
| Figure 8.2 The number of individuals of selected macroinvertebrate taxa as observed in each sample at each site in the river Mangdechu 25.04.1998..... | 33 |
| Figure 8.3 The number of species of mayflies, stoneflies and caddisflies (EPT; Ephemeroptera, Plecoptera, Trichoptera) observed at each site in the river Mangdechu 25.04.1998..... | 34 |
| Figure 8.4 The diversity of mayflies+stoneflies+caddisflies expressed as Shannon-Wiener diversity index at each site in the river Mangdechu 25.04.1998..... | 34 |

List over Tables

| | |
|--|----|
| Table 3.1 Water quality measurements in Mangdechu at Jeezam Bridge (upstream of Trongsa Town) the 24th of August 1997. “Pilot National Baseline Water Quality Survey in Bhutan (August - October 1997)” carried out for the National Environmental Commission..... | 14 |
| Table 6.1 Some in Situ measurements of water quality in Mangdechu 24-27 April 1998..... | 17 |
| Table 6.2 Thermostable coliforme bacteria in Mangdechu the 26 th of April 1998. | 22 |
| Table 7.1 Incidences of waterborne diseases and status for water supply and sanitation for the Trongsa district (dzongkhag) in 1997. Source: District Medical Officer, Trongsa..... | 24 |
| Table 7.2 Water supply and garbage fees (Nu) per month in Trongsa town for residential buildings.. | 27 |
| Table 8.1 Species composition and relative dominance of the periphyton samples collected from Mangdechu River 24-27 th April 1998. | x |
| = observed, xx = common, xxx = very common, xxxx = dominating. NB: This reflects the relative abundance in the samples, not in the river. For abundance in the river, see text. | 3 |
| 2 | |
| Table 9.1 Approximate costs for the mitigation measures necessary to take care of aquatic environment, water quality, worker’s camp drinking water and sanitation. | 39 |
| Table 12.1 Water quality of Mangdechu. Values from April represent dry season, and values from June represent rainy season. | 44 |
| Table 12.2 Mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) at 3 sites in the river Mangde Chu 25.04.1998. Method: stirring approximately 1 m ² of the substrate by hand, handnet with mesh size 250 µm. | 45 |
| Table 12.3 Benthic macroinvertebrates at 3 sites in the river Mangde Chu 25.04.1998. Method: stirring approximately 1 m ² of the substrate by hand, handnet with mesh size 250 µm..... | 46 |
| Table 12.4 Recommended Criterias for Drinking Water and Raw Water Supplies in Bhutan | 46 |
| Table 12.5 Bacteriological drinking water qulity criteria developed by WHO..... | 47 |

1 Executive summary

1.1 Water quality

The Mangdechu River has soft water (conductivity 4-5 mS/m, Calcium 6-8 mg Ca/l), slightly alkaline reaction (pH 7.3-7.5). Periodically, the river has high sediment load. The water is cold and impacted by snow melt from higher regions in the Himalayas.

During the dry season the water was relatively clear with turbidity of 1.7-1.4 FTU. On the sampling day in the rainy season (June 30th) the water was very turbid with turbidity values varying from 41-120 FTU. The turbidity was accompanied by a content of suspended solids 5-6 mg/l in low flow periods and of nearly 400 mg/l in high flow periods. Highest concentration of suspended sediments was observed in January 1997 with 1.2 g/l. The particles causing the turbidity were inorganic soil particles.

The water had low colour 20-30 mg Pt/l, and low content of organic matter, TOC 2-3 mgC/l. The plant nutrients, phosphorus and nitrogen, showed very low values, and indicate a low productive river (Total P = 5-6 µgP/l (dry season), Total N = 250-285 µgN/l, NO₃ = 140-200 µg N/l). The phosphorus increased considerably during the wet season. This increase is not due to pollution, but to the fact that the erosion products (soil particles) contain a lot of natural adsorbed phosphorus. The low nitrogen levels indicate also that the mountain areas of the river catchment are little impacted by atmospheric fallout of air transported pollutants.

The water is slightly contaminated by faecal coliform bacteria (44 °C Coli equals 35 bact. per 100 ml), mainly arising from sewage effluents from Trongsa town.

1.2 Water supply and sanitation

In the villages a great majority (80%) of the households have tapped water from relatively safe ground water sources. This relatively high coverage is due to implementation of the governmental Rural Water Supply and Sanitation (RWSS) Programme which was partly funded by UNICEF. The villagers are recommended to boil their drinking water, particularly in the rainy season. Trongsa district has a plan that aims at providing all inhabitants with tapped drinking water by the end of year 2000.

The sanitation system consists of different kinds of latrines. The most common is pit latrine with slab. Soak pit latrines with "pour-flush" is also common, and is increasing in popularity. Each house is equipped with a latrine which is located 10-15 m from the house. The latrines are built-in by simple roof and walls.

The drinking water sources for Trongsa town are 2 streams uphill from the town. These sources often contain high amounts of coliform bacteria, and several incidences of diarrhoea occur, particularly during the rainy season. The inhabitants are recommended to boil their drinking water.

In Trongsa town the hotels and some other buildings have water closet. The grey water and the black water are piped separately. The grey water goes to an open canal which also drains the house and collects the roof water. This canal ends in the terrain behind the house. The toilet water (black water) goes via a septic tank to a soak pit.

The sanitary system for Trongsa town is far from satisfactory. Most soak pits are overloaded and leakage water drains to the stream which enters Mangdechu just downstream. In addition, septic tanks are often emptied directly into the stream.

1.3 Aquatic Flora and Fauna

Macrophytes, phytoplankton and zooplankton were not found in the river. Periphyton was the most prominent primary producer in the river ecosystem, of which the thin and slippery diatom cover on the stones was the most important. This cover was heavily loaded with silt, which is a stress factor for efficient production. Most species were typical for cold unpolluted rivers.

The bottom dwelling animals were the most important secondary producer in the river food chain. The fauna was richer at the damsite and reservoir inlet compared to the tailrace area. This applied both for biomass and diversity. Leaves from the overhanging jungle gave a significant food addition to the bottom animals at the 2 uppermost stations. Less fish (=less predation) could also be an explanation for the richer fauna in the reservoir area, as compared to the tailrace area (Hvidtsten 1998).

Ephemeroptera, Trichoptera, and Chironomids were the most important bottom animal groups.

1.4 Impacts on water quality and aquatic life

The largest impact will occur in the 5-6 km long river stretch downstream of the dam and down to the confluence with Chendebjichu. There are few water use interests connected to this river stretch. However, in the dry season it is important for drinking water supply for wildlife and pasturing cows, as well as some fishing. To take care of these interests and biodiversity values, it is necessary with a minimum release of water over the dam.

In the tailrace area, full utilisation of peaking production will result in sudden water flow rises from 5-6 m³/s to 80 m³/s when the water is switched on and sudden decreases when the water is switched off. This will completely destroy aquatic life for many kilometres downstream.

There is not any scope of a good fish production in the reservoir area. The comprehensive water level fluctuations will be a main constraint. In the first years of regulation, the reservoir shoreline will be heavily eroded.

In the low flow stretch from the dam and down to tailrace, the water will be susceptible to bacterial contamination due to small dilution volume. The temperature will be higher than to day. Downstream of the tailrace the river temperature will be somewhat lower.

Increased population, particularly the labour camps during the construction period, is likely to impact the water quality in the river negatively by sanitary effluents/leakages.

Tunnel water and erosion from spoil deposits and dam construction may impact the river water quality negatively with load of inorganic particles, and construction chemicals.

1.5 Impacts on water supply and sanitation

The project will increase the population in the district. The increase is believed to take place in Throngsa town, in the labour and operation camp at the tailrace area, and in the construction camp at damsite. This will impose need for adequate drinking water supply and sanitary devices to cover this increase.

1.6 Mitigation measures

Minimum release

To take care of the user interests and the ecological value of the river stretch from damsite to the confluence with Chendebjichu River, a minimum release in the size of 1.5-3 m³/s is needed.

Camps water supply and sanitary devices

The labour camps must be equipped with adequate water supply and sanitary devices.

Trongsa town water supply and sanitary rehabilitation

The population in Trongsa is expected to increase and both the water supply and the sanitary system should be rehabilitated. This will include infiltration and treatment of drinking water, and collection and treatment of sanitary effluents.

Fuel, oil, and chemical storage areas

At the dam site and the tailrace there should be developed special storage areas for fuel and construction chemicals. The area should have a collection system in case of accidental large spillages.

Location of the labour camp at dam site

The camp at dam site should, if possible, be located in a way that allows possible pollution discharges to reach the river upstream of the dam. This to protect the vulnerable minimum release stretch.

Prevention of formation of supersaturation of nitrogen

Air should not be allowed to enter the diversion tunnel. The intake must be submerged at all time. Extra intakes along the diversion route should not be allowed.

Sufficient drainage of spoil deposits to prevent erosion

To prevent erosion material from the spoil deposits to pollute the river, the spoil deposits should be adequately drained.

Sedimentation and infiltration of tunnel water during construction

During the construction the tunnel water must pass a sedimentation basin and preferentially be infiltrated in the terrain afterwards. This to prevent too much sediment load to enter the river.

Operation arrangements at the tailrace entrance

It should be developed an adequate operation strategy to prevent too rapid changes in the water flow, if full peaking production will take place in the low flow season.

2 Introduction

2.1 Background

The Royal Government of Bhutan has requested the Government of Norway to provide bilateral funding to carry out a Feasibility Study for the Mangdechu Hydroelectric Project in Trongsa, Central Bhutan. In addition to the Technical and Economic Study, lead by Norconsult, the Main Consultant (MC), the Feasibility Study comprise an independent Environmental and Socio-economic Impact Assessment Study. This EIA is undertaken by the consortium SE/NIVA/NODE, hereinafter called the Environmental Consultant (EC).

NIVA's part of the EIA comprises the 2 items:

- Water Quality and Sanitation
- Aquatic Flora and Fauna

2.2 Short description of the river and the hydropower development

Upper Mangdechu River is situated mostly in Trongsa district of Central Bhutan. The main river originates from a big outlet glacier coming down from the ice-fields around Gangkar Phunsum mountain range in the Northern Bhutan. The river flows south and passes the Trongsa town area at about 1750 m above sea level. It then traverses in south-westerly direction for a total of approximately 9.5 km where it confluences with Chendebji river in between the project dam site and tailrace location. Then it traverses in south-east direction receiving other small tributaries. The river flows into Southern Bhutan where it reaches Manas River and the combined rivers flows as Manas River into the Indian State of Assam to eventually join the Bramaputra river. The total catchment area of Mangdechu River is 4444 km², where as the upper part that is going to be utilised for hydropower production is 1523 km². The river in the project area is shown in Figure 2.1.



Figure 2.1 Mangdechu river and the location of the project area.

The intake dam will be situated just downstream of Trongsa Town. Being approximately 50 m high, it will fill up a small reservoir of about 86000 m³. The water will be diverted via a 12.5 km long tunnel to a power station at Langthel.

The powerhouse will be situated 1.3 km inside the mountain, and the water will enter Mangdechu via a tailrace tunnel of the same length. The height difference between the intake dam and the power station (gross head) is 692 m. The design discharge is 76 m³/s. Installed capacity will be 440 MW.

Mangdechu has an annual mean flow at the diversion dam of about 62,5 m³/s. Monthly mean discharge is lowest in February with 13 m³/s and highest in August with 170 m³/s, see Figure 2.2.

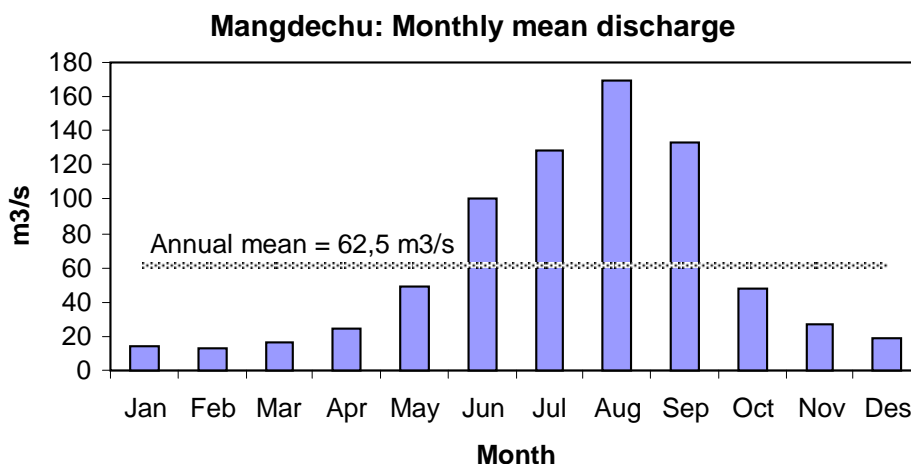


Figure 2.2 Monthly mean water flow in Mangdechu River at the dams site.

The water flow in Mangdechu will be strongly reduced between the dams site and the tailrace, and particularly down to the first tributary, Chendebjichu, a river stretch of 5-6 km.

2.3 Aim of the Study

- Review possible existing literature on water quality of Mangdechu river.
- Describe the water quality of the Mangdechu river in the project area.
- Register the user interests (use categories) connected to the river.
- Assess to what degree the hydropower regulation scheme will affect the water quality, and to what extent this impact will conflict with the user interests.
- Describe the water supply and sanitation in the area and assess possible impacts on these user interests, with particular emphasis on waterborne diseases.
- Describe the aquatic flora and fauna of the Mangdechu river (fish is taken care of in a separate study).
- Propose mitigation measures to minimise the ecological impact and the conflict with important user interests. Assessing the need for minimum water release over the dam is a central point in this respect.

3 Review of existing literature

According to the prefeasibility study, very little information is available concerning the water quality of Mangdechu River. In the meeting with Senior Governmental Officials (Appendix 2.4 page 15 in the prefeasibility report), it is stated that it should be carried out a detailed limnological study in the waterbodies in the damsite area to assess their potential / feasibility for fish culture.

During the field work period April/May and September 1998 several institutions were visited in a search for both water quality analytical results and analytical facilities, as well as literature:

Division of Power, Main Office
 Division of Power, Sediment Lab Unit
 Public Health Laboratory Thimphu
 Soil and Plant Laboratory Simtokha, Ministry of Agriculture
 Meeting with dr. Damber Kumar Nirkola, District Medical Officer, at Trongsa Hospital
 The Lab at the Hospital of Trongsa
 Meeting with the District Engineer of Trongsa, Mr. Phuentcho Dorji.
 DANIDA, Thimphu Office.
 Jimba Consultancy Services Ltd., Thimphu

Concerning water quality analysis the Sediment Lab Unit at DOP had a set up for measurement of suspended solids, and at the moment they were monitoring the sediment transport of Mangdechu River as part of the technical hydropower project planning. The hospitals both in Thimphu and in Trongsa were able to perform bacteriological analyses, and conducted analyses of drinking water. They had, however, not performed any analyses in Mangdechu River prior to this project.

Concerning existing water quality data, the recent report "Pilot National Baseline Water Quality Survey in Bhutan (August - October 1997)" carried out for the National Environmental Commission, gives some data for the Mangdechu River, at Jeezam Bridge just upstream of Trongsa, se Table 3.1.

Table 3.1 Water quality measurements in Mangdechu at Jeezam Bridge (upstream of Trongsa Town) the 24th of August 1997. "Pilot National Baseline Water Quality Survey in Bhutan (August - October 1997)" carried out for the National Environmental Commission

| Parameter | Unit | Value |
|-------------------|-------|-------|
| Dissolved Oxygen | mg/l | 8.5 |
| Oxygen saturation | % | 80.6 |
| Temperature | °C | 12.5 |
| pH | | 7.93 |
| Conductivity | µS/cm | 36.3 |

In addition to these data there is an ongoing monitoring of the sediment load of the river carried out by Civ. Eng. Pasupati Sharma at DoP Sediment Lab Unit on commission of the Main Consultant. These data are not yet published, but we have been allowed to look into the database and the data indicate that the river can during the rainy season carry fairly high amounts of sediments. Highest record so far is approximately 1200 mg/l suspended solids, January 1997.

The above cited results, which are the only that existed before this study, indicate that Mangdechu River has soft water of low temperature and a high oxygen content. In periods the river may have high sediment load. However, these data do not, to any extent, give a sufficient description of the water quality compared to the need in the Environmental Impact Assessment Study.

No data is given on main ionic composition, neither any data describing bacteriological pollution.

4 Assessing water user interest in Mangdechu River

4.1 Introduction

Relevant water use categories in a river like Mangdechu could be:

- drinking water supply
- water supply for household animals
- fisheries
- washing cloths
- bathing
- irrigation
- recipient
- hydropower
- drinking water for wild life

For most human water use categories the water quality and the water amount have to be within certain limits. In addition, water quality is one of the most important factors regulating the aquatic life in a river. Knowledge of the water quality is therefore crucial for an optimal and environmentally sound water management.

4.2 Assessment of the existing water use interests in Mangdechu

This assessment was performed both by direct questions (questionnaires and interviews) to the local population conducted by the socio-economic study, consultation meetings with the villagers as well as several meetings with officials of Trongsa Dzong.

The user interests were less comprehensive than originally believed, and the local population was less depending on the river than often is the case in hydropower development projects. The river was not used for drinking water. It was not used for irrigation. Fishing took place only to a minor extent, the same applied to bathing and washing cloths. The local population did not find that the planned hydropower development scheme conflicted with their interests to any significant extent.

Of the listed use categories in section 4.1 the following items seem to be the existing user interest for the population of Trongsa and the project influence area:

- Water supply for household animals (animals on pasture)
- Water supply for wildlife
- Recipient of wastewater
- Fish and aquatic life

However, the local population looks very much forward to get electricity, and they are not very aware of what might be possible future interests connected to the river.

5 Field work: Water Quality in Mangdechu River

5.1 Sampling stations

Water samples were taken from the Mangdechu River according to the programme:

- Upstream the future reservoir
- At the damsite
- At the outlet area for the tailrace canal

The sites for the new diversion scheme cited in the Minutes of Meeting (DOP March 21th 1998) were chosen.

5.2 Water Quality Parameters and analysis

Samples were taken for the following parameter groups:

- Suspended solids
- Coliform bacteria
- Basic water chemistry

As there are no industry effluents in the catchment, the river water was not analysed for heavy metals or organic micropollutants.

Suspended solids:

Samples were taken from the three stations in 5 litre cans. These were brought back to Thimphu for analysis at the Sediment Lab Unit at DOP.

Basic water chemistry:

Water samples for the following parameters were brought back to Norway to be analysed at Norwegian Institute for Water Research (NIVA): pH, Conductivity, Colour, Turbidity, TOC, Total Phosphorus, Total Nitrogen, NO₃, Ca, Mg, Na, K, Alkalinity, Cl, SO₄.

Coliform bacteria:

Samples for coliform bacteria were taken on pre-sterilised bottles from all three stations on Sunday the 26th of August, stored over night in the refrigerator at the Tourist Lodge in Trongsa, and delivered to the Lab at the Trongsa Hospital the morning afterwards for analysis of 44 °C coliform bacteria.

6 Results: Water Quality Study

6.1 *In-Situ Measurements*

Using a pH/Temperature meter kindly lent out by Jimba Consultants, the following measurements were made, Table 6.1.

Table 6.1 Some in Situ measurements of water quality in Mangdechu 24-27 April 1998

| Station | Temp. °C | pH |
|---|-----------------|-----------|
| Upstream the future reservoir | 11.4 | 6.35 |
| At the damsite | 11.4 | 6.35 |
| At the outlet area for the tailrace canal | 15.4 | 6.93 |

From these data it can be seen that the water temperature increases significantly on the way from the reservoir down to the tailrace area. This is partly due to warmer climate at the tailrace area (Langthel) but it is also a result of entrance of warmer tributaries which is not impacted by snowmelt like Mangdechu River. The most important of these tributaries is Chendebjichu. pH also increases on the way down to the tailrace area, a function primarily due to inflow of more alkaline waters from Chendebjichu.

The pH values measured with the in-situ instrument gave lower values than the laboratory determinations, see Table 11.1 in the appendix. This is most likely due to un-calibrated/mal-functioning electrode of the field instrument. However, the relative difference between the stations should be correct.

6.2 *General water quality parameters*

Five general water quality parameters, pH, conductivity, colour, TOC (total organic carbon) and turbidity are given in Figure 6.1.

The water is relatively soft, with a slightly alkaline reaction. Both pH and conductivity increase from the damsite and down to the tailrace, due to influx of more alkaline waters from the tributaries. With respect to conductivity there is little difference between the wet and dry season.

The colour of the river is around 20 mgPt/l in the dry season, and increases to around 35 in the wet season. The river is little- to moderately impacted by soil humic matter, the brownish stain that is particularly appearing in rivers draining forests and boggy areas.

The turbidity of the river is very variable, ranging from 1.5 FTU in the dry season to 120 FTU in the wet season, indicating large variations in sediment load. This is due to high degree of erodability in the catchment area. Sudden rainfalls and snow-melts may in short time change the river from a clear water river to a greyish-brown muddy appearance. With a turbidity of 120 FTU the water will cause problems for most use categories, other than irrigation and concrete additions, etc.

Total organic carbon varies from 2 mg C/l in the dry season to above 3 mg C/l in the wet season. The variation correlates well with the colour which indicates that the carbon mainly consists of dissolved compounds. This is in agreement with the findings that almost all the particulate matter consisted of inorganic particles (see paragraph dealing with suspended sediments), and that no free floating algae (plankton) were observed (see the chapter dealing with aquatic flora and fauna).

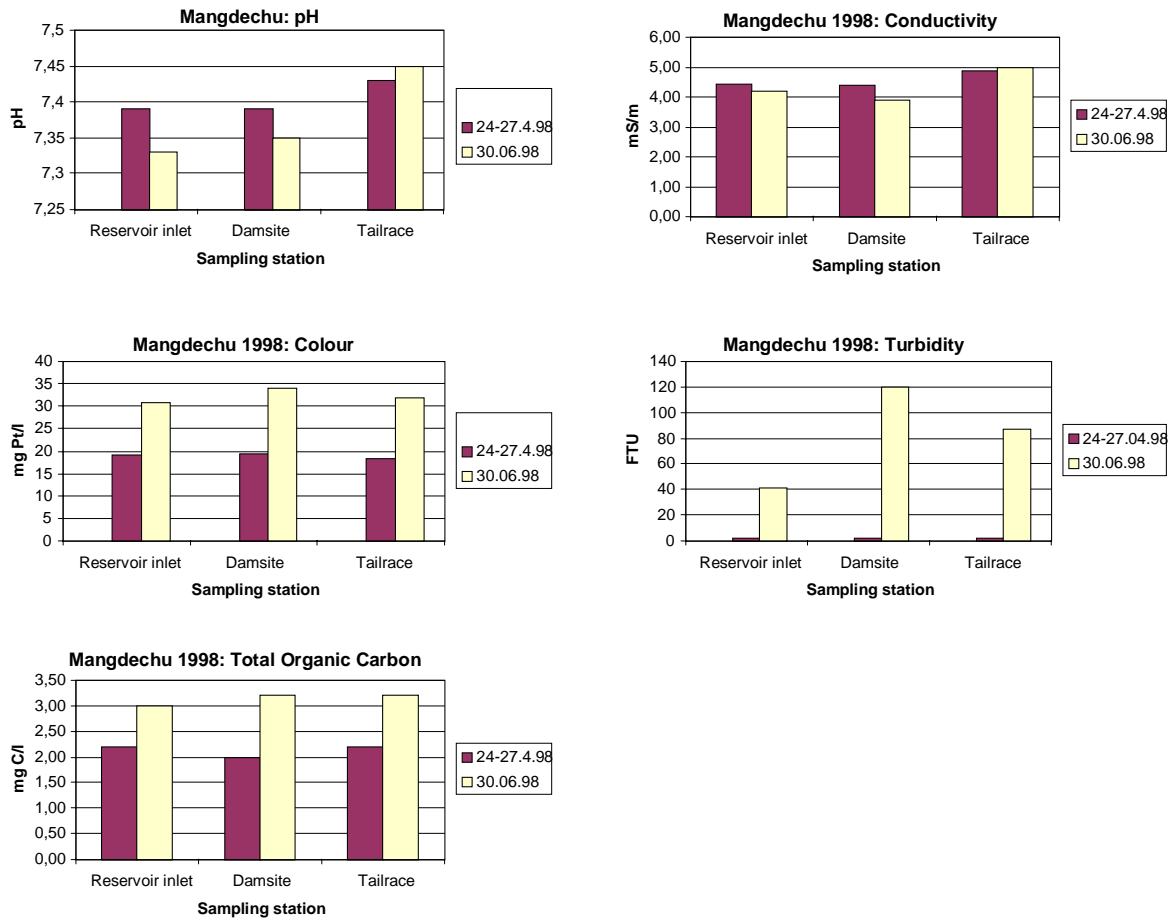


Figure 6.1 Mangdechu 1998. Some general water quality parameters. The April values represent a dry period, while the June values represent the rainy season.

6.3 Suspended solids

Mangdechu River is periodically heavily impacted by erosion material. Visually the water can appear perfectly clear in the dry season and look completely grey at other occasions due to heavy sediment load. Periods of rainfall and snow-melt upstream results in immediate increase in sediment load. The hillsides along the river are steep and contain thick layers of easily erodible soil. Every year several landslides occur along the valley. The summer 1998 was particularly wet and many slides took place. Figure 6.2 shows the monthly load and the mean monthly concentration of particulate matter in the river water for 1996 and 1997.

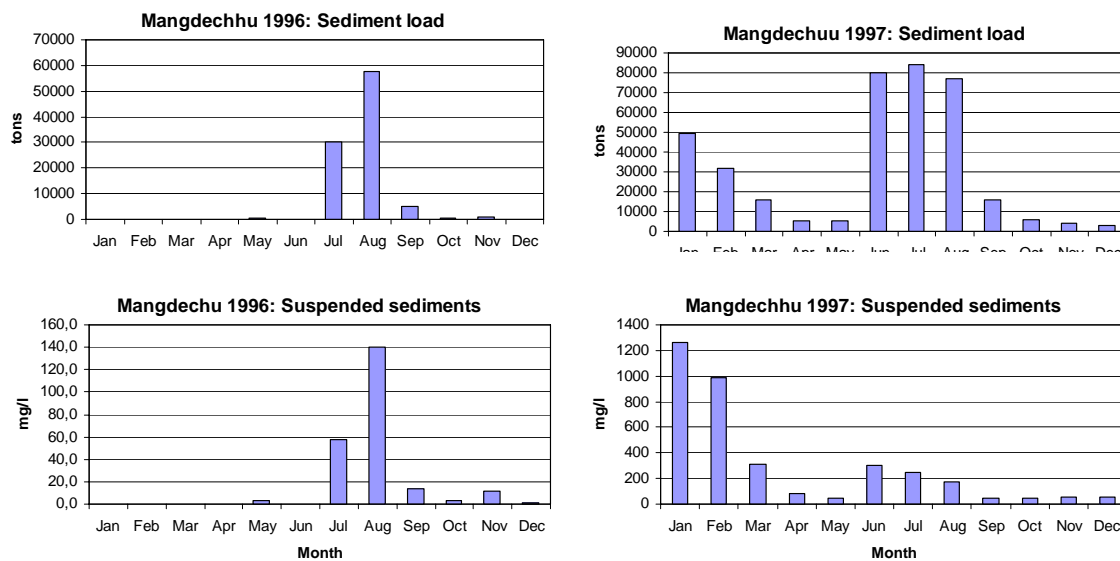


Figure 6.2 Suspended sediments in Mangdechu at Jeezam Bridge (the road crossing just upstream Trongsa) 1996 and 1997. The upper panel shows monthly transport values, the lower panel shows monthly mean concentrations. Data from DOP’s monitoring, month without column = lack of data.

Figure 6.3 shows the concentration of suspended solids measured during the field work of the EIA study. In the left panel is shown the total suspended solids during dry and wet season, while in the right panel the total content is split into organic and inorganic fractions.

The concentration was only 6 mg/l in April in a low flow period, and increased to 380 mg/l in late June during high flow conditions.

From the right panel it becomes clear that nearly all the suspended material consist of inorganic particles, i.e. erosion products.

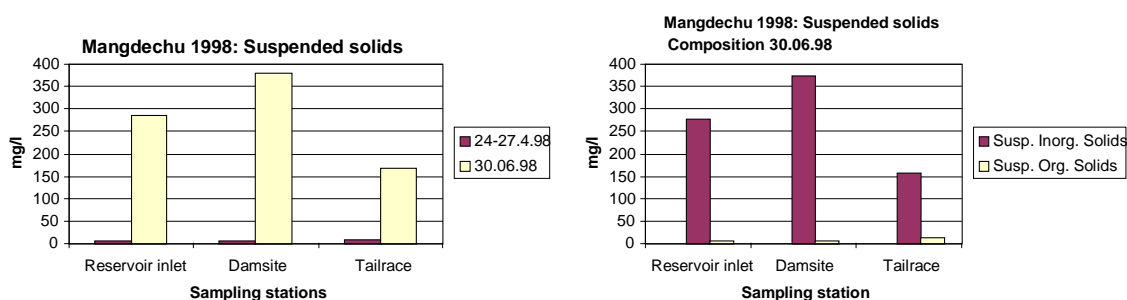


Figure 6.3 Concentration of suspended solids in Mangdechu River observed during the water quality sampling. Left panel shows the difference between wet and dry season, while the right panel shows the inorganic and organic fraction of the suspended solids in the river water in June 30-98 (wet season).

6.4 Nutrients

Figure 6.4 shows the concentration of the nutrients phosphorus and nitrogen. The concentration of total phosphorus in this river is completely determined by the content of erosion material, and is quite insignificantly impacted by anthropogenic effluents. In the dry, low flow season the concentration of total phosphorus was only 5-6 $\mu\text{g P/l}$, while in the wet season it increased up to as high value as 150 $\mu\text{g P/l}$. This high concentration of erosion derived total-P is firmly bound to soil particles and is only to a minor extent available to aquatic plants. High turbidity during erosion periods of high P-concentrations also reduces the plants possibility to utilise the high total-P concentrations during the wet season.

As well as the low total-P concentration during low flow periods, the low values of total nitrogen and nitrate clearly show the nutrient poor status (oligotrophic) of Mangdechu. Nitrogen is not attracted to particles, and is therefore not increasing due to erosion activity. For that reason there is not a significant difference between values from the wet and the dry season. Almost all the nitrogen is in the form of nitrate, which indicate low uptake by algae and other aquatic plants.

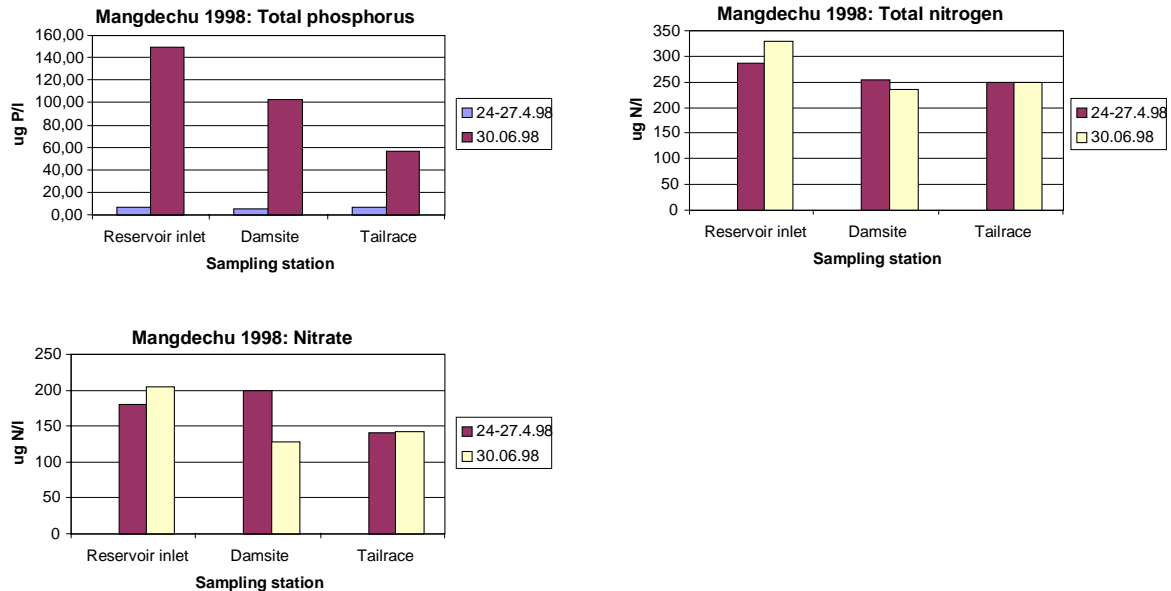


Figure 6.4 Mangdechu 1998. Observed concentrations of the plant nutrients phosphorus and nitrogen. The April values represent the dry season, while the June values represent the rainy season.

6.5 Major cations

The concentrations of the major cations, Calcium, Magnesia, Sodium and Potassium, are shown in Figure 6.5.

Ca varies between 6 and 8 mg Ca/l which is a fairly low level compared to other rivers of Himalaya. There is apparently restricted abundance of calciferous rocks in Mangdechu's upper catchment area.

Low levels of sodium indicates that the area are not impacted much from depositions of sea salt aerosols.

The highly mobile ion Na has very little particle affinity, and the concentration during high flow is diluted. For the other less mobile ions there is an increase in the concentration as the erosion increases during periods of high flow.

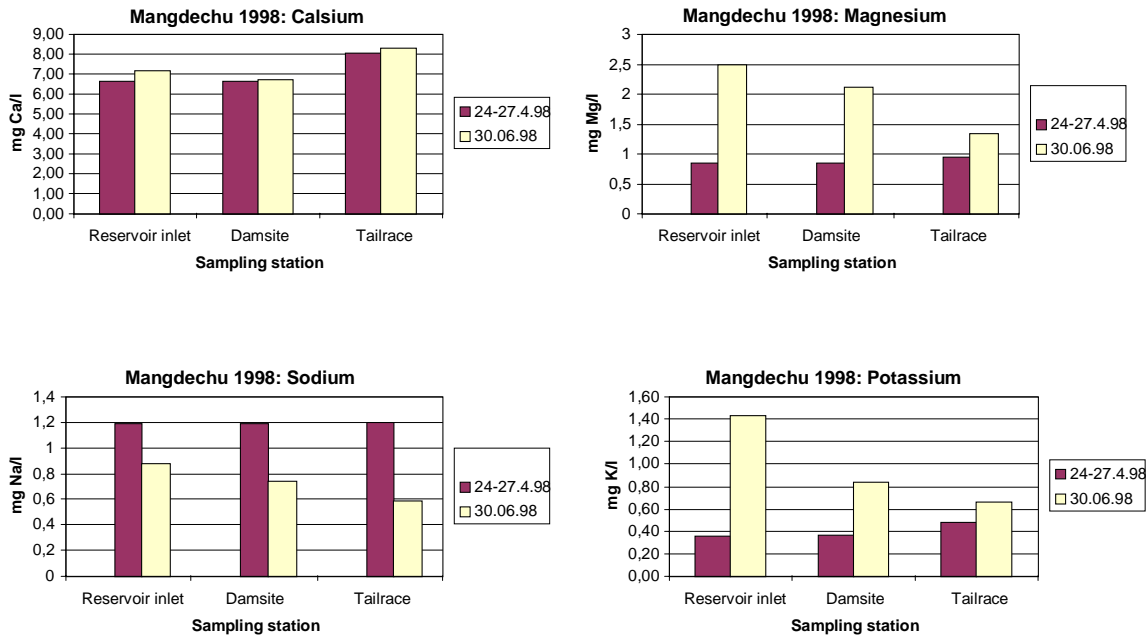


Figure 6.5 Main cations in Mangdechu during the water quality sampling (April data represents dry season, while June data represent wet season).

6.6 Major anions

The concentrations of the major anions, i.e. ions that balance the major cations, are given in Figure 6.6. The alkalinity consists of bicarbonate and carbonate, and the relatively high level makes the water well protected against acidification. It also implies that the water is not aggressive against concrete material, and is well suited as concrete additive.

Sulphate and chloride is extremely low. The content indicates that there is not much gypsum rocks in the catchment, neither boggy landscapes of any extent, nor deposition of acid rain or sea salt components.

The slightly higher content of chloride at the two uppermost stations indicates impact from discharges from Trongsa Town. Chloride is extremely mobile through soils so the consumption of salt in households is easily observed in the receiving waters. Chloride is, however, harmless to the environment in the concentrations observed in Mangdechu.

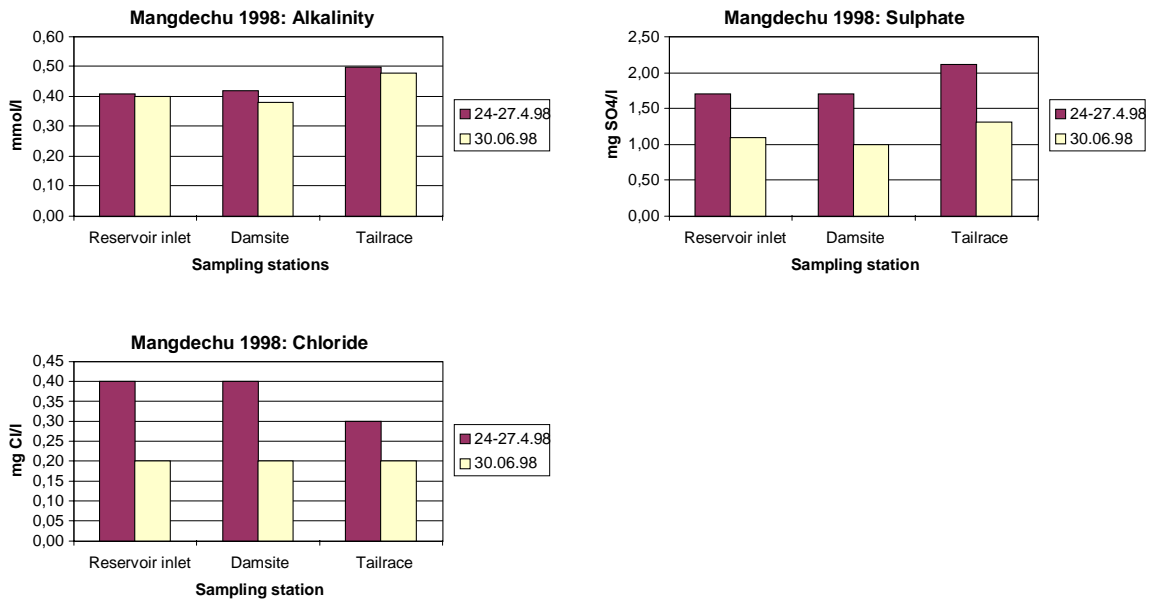


Figure 6.6 Main anions in Mangdechu during the water quality sampling (April data represent the dry season, while June data represent the wet season).

6.7 Bacterial analysis

The samples were analysed for thermostable coliform bacteria, the results are given in Table 6.2.

Table 6.2 Thermostable coliforme bacteria in Mangdechu the 26th of April 1998.

| Station | Inlet Reservoir | Damsite | Tailrace |
|---|-----------------|---------|----------|
| Thermostable Coliforme bacteria No per 100 ml | 35 | 34 | 32 |

The analysis gave counts from 32 to 35 thermostable coliforme bacteria per 100 ml. The bacteria analysis from the 3 stations showed that the river is polluted by coliforme bacteria, i.e. bacteria arising from the colon of warm blooded animals. Most likely this comes from human discharges. The sanitary engineer confirmed that much of the sewage from Trongsa entered the stream running through the town and enters Mangdechu just upstream our uppermost sampling station.

6.8 Impacts on Water Quality

Diversion of the water from Mangdechu will give reduced water flow in the river downstream the dam all the way down to the tailrace outlet. On this stretch the water will be more polluted than it was before, and the use for human consumption may impose a health concern. Likewise the reduction in flow will reduce the biological production of the river. This implies both lower organisms and fish.

It is likely that the temperature in the low flow section of the river will increase as Chendebjichu and the other tributaries entering downstream the dam is less impacted by snowmelt than is Mangdechu. Likewise the summer temperature downstream tailrace may be reduced due to lack of sun heating of

the river water that is diverted under ground. During the winter this effect will be less. It is difficult to assess the magnitude of such temperature changes. It is, however, not expected that it will result in any serious ecological problems.

The new diversion scheme implies that it will be approximately 690 m difference in elevation between the dam and the turbine outlet. The diverted water will be exposed to high pressure. If the intake opening is allowed to surge air, or turbulent water (with air bubbles) is entering the diversion canal, for example via intake tunnels (catching brooks and rivulets) along the diversion tunnel, this can result in supersaturating of nitrogen and other gasses. This has caused fish kill in several rivers. The best mitigation measure against this phenomenon is to keep the diversion tunnel full at any time, and don't feed it with turbulent water intakes along the diversion route. A closed swinging chamber may also result in some supersaturating conditions.

In Trongsa town it is expected that the population will increase, both due to the project, and in general. As there is no adequate well functioning sanitary system for the town, the increase in population will give negative impact on the water quality of Mangdechu River.

At the tailrace area it will be established a construction labour camp, and at a later stage a permanent labour camp for the operating and maintenance personnel. At the damsite there will be established a temporary labour camp. These camps may impact the water quality negatively, particularly by discharges of sanitary effluents which can accomplish health risk in downstream areas.

The river may be affected by discharges of fuel, oil and construction chemicals.

Quarries, tunnel blasting, spoil deposit storages, construction and adit roads will increase the erosion load to the river.

The project will give an increased load of nitrogen compounds to Mangdechu. Blasting with ammonium nitrate gives high runoff of nitrate and ammonium. Combined with use of concrete, particularly the spray concrete type, in tunnel security work, gives very high pH (up to 13) in the tunnel water. This may result in transforming ammonium into ammonia which in small recipients have been shown to cause fish kill.

6.9 Mitigation measures

As there is a close relationship between water quality and aquatic flora and fauna, the need for mitigating measures is given a joint treatment in section 9.

7 Water Supply and Sanitation

7.1 Introduction

As a consequence of the development of hydropower in the Mangdechhu, the population in the Trongsa district is expected to increase. Temporary camps during construction and permanent camps for staff operating the hydropower plant will be established, and increased population in the area due to increased activity is also expected. The increased population will demand appropriate water supply and sanitation facilities.

Water borne diseases like e.g. diarrhoea, dysentery, are a major health problem in the Trongsa district as for the rest of Bhutan (see Table 7.1). Minor epidemic diseases like cholera and typhoid have also been registered in the area lately.

Table 7.1 Incidences of waterborne diseases and status for water supply and sanitation for the Trongsa district (dzongkhag) in 1997. Source: District Medical Officer, Trongsa.

| | Trongsa hospital | Kuengarabten BHU ¹ | Langthel BHU | Bemji BHU | Nabji BHU | Total Trongsa |
|-------------------------------------|------------------|-------------------------------|--------------|-----------|-----------|---------------|
| General: | | | | | | |
| Total population ² | 3791 | 2905 | 3846 | 1205 | 1226 | 12973 |
| Household | 335 | 395 | 334 | 140 | 188 | 659 |
| Waterborne diseases: | | | | | | |
| Diarrhoea/ Dysentery | 681 | 706 | 754 | 150 | 46 | 2337 |
| Helminthic infections | 314 | 498 | 863 | 32 | 68 | 1775 |
| Cholera | 0 | 0 | 0 | 0 | 0 | 0 |
| Typhoid | 0 | 7 | 0 | 0 | 1 | 8 |
| Water supply and sanitation: | | | | | | |
| Coverage (%) latrine | 74 | 92 | 99 | 89 | 100 | 90 |
| Coverage (%) water supply | 100 | 67 | 100 | 59 | 96 | 86 |
| Coverage (%) RWSS | 82 | 67 | 98 | 59 | 96 | 81 |

Provision of adequate water supply and sanitation facilities to the rural areas in the Trongsa district has been given priority. This has resulted in generally improved health situation and reduction of waterborne diseases in the rural areas. The water supply and sanitation system in Trongsa town is, however, not appropriate. No funds are allocated in the 8th Five-Year Plan to improve the facilities in Trongsa town. The users pay fees for water supply and sanitation, which recover some of the costs.

In 1998, the responsibility for provision of water supply and sanitation systems in the rural areas shifted from the Department of Public Works and Housing to the Department of Health in Bhutan. The

¹ BHU: Basic Health Unit

² Total population means only the people who are registered at the hospital or at the health units.

objective is to reach complete coverage of adequate water supply in the Trongsa district by year 2000. Beside water supply and sanitation in rural areas, the Public Health Engineering Unit is responsible for survey of water sources, design and construction of water supply systems, as well as operating and maintenance of the various systems.

Tentative recommendations for drinking water quality and water used for agricultural irrigation water have been developed for Bhutan. Drinking water is locally considered acceptable if the concentration of faecal coliform bacteria is less than 10. Bacteriological drinking water quality criteria have not been developed specific for Bhutan. However, the WHO's criteria have been recommended in Bhutan, saying that faecal coliform bacteria must not be detectable in the drinking water (see Annex I). The suitability of water for irrigation is determined by concentrations of dissolved salts, toxic substances and pathogens.

7.2 Rural areas

7.2.1 Rural water supply: present situation

About 80 % of the population in the rural areas have access to tapped water with a gravity fed system consisting of an intake tank, a pressure tank (if high altitude difference) and one or more piped taps. This relatively high coverage is due to implementation of the governmental Rural Water Supply and Sanitation (RWSS) programme which is partly funded by UNICEF. The water intake source is preferably spring (ground) water, which is most common, and alternatively stream water from up in the hillside above settlements. People in the rural areas are encouraged to boil their drinking water. Monitoring of the bacteria content in the intake water is being performed before construction of the pipelines and tanks.

A standardisation manual on rural water supply has been prepared by the Ministry of Health and Education, Public Health Engineering Unit, in Bhutan. These standards include spring intakes without collecting tank, stream intakes, collection tank, pipe line valves, sedimentation tanks, reservoir tanks, pressure tanks and public tap-stands.

7.2.2 Rural sanitation: present situation

Most households in the rural area of Trongsa district have at least a simple pit latrine. When a simple pit latrine is filled up, it is covered by organic matter like leaves, and another pit (hole) will be dug.

The soak pit latrine, which consists of a septic tank connected to a soak pit, is the most common sanitation facility in the rural area. Water is needed to flush the toilet. The soak pit is filled with stones that provide infiltration of the waste water into the ground. During the rainy season, the soak pit latrine may be flushed, and waste water may come up to the surface and lead to inadequate conditions and outbreak of diseases.

A relatively new design used in the rural area is the pour flush latrine that has two tanks with a valve that can shift from one tank to the other. Water is required to flush the toilet. The walls in the tanks are build of stones that provide infiltration of the waste water. It takes about 4 years to fill up one tank with normal use by one household. After some months with degradation/composting, the waste will turn into soil, which then is spread on the fields.

7.2.3 Impacts of the project

Since the Mangdechhu River is not used as a source of drinking water or as primary recipient for wastewater, the project will have no direct impacts on the quality of water supply and sanitation

facilities in the rural areas along the river. As an indirect impact of the project, more people are expected to settle down in the same area where camps will be established due to business opportunities, especially close to the more permanent colony by the tailrace outlet. In that sense, adequate sources for drinking water and systems for sanitation will be needed. Furthermore, complete coverage of adequate water supply and sanitation is expected to be reached before construction of the hydropower plant starts.

7.2.4 Mitigation measures

Regulations and facilities for both water supply and sanitation need to be developed as the amount of people is increasing.

If the people running shops, restaurants etc. have no fields to spread the composted waste from soak pit latrines, co-operation with the local farmers need to be established.

Assistance should be provided to the district administration in construction and maintenance of the water supply and sanitation facilities if the complete coverage objective is not reached before construction commences.

7.2.5 Monitoring

Monitoring of the drinking water needs to be performed on a regular basis in areas with increased human activities.

7.2.6 Costs of mitigation measures

A system of user fees should gradually be implemented to recoup some of the costs regarding water supply and sanitation systems in the rural areas. Since complete coverage is expected by year 2000, no mitigation costs are foreseen.

7.3 Trongsa town (urban area)

7.3.1 Urban water supply: present situation

All inhabitants in Trongsa town have access to tapped water supply. The water quality is, however, very bad and the drinking water in the present situation needs to be boiled. The intake is from a stream about three km from the town. Shortage of water in Trongsa town may happen during the dry season (October-January). The drinking water quality regarding bacteriological content is monitored on a regular basis four times a year.

The inhabitants of Trongsa town pay water supply fees. The fees are set according to the size of the house as presented in Table 7.2.

Table 7.2 Water supply and garbage fees (Nu) per month in Trongsa town for residential buildings.

| Type of building | | Water | Garbage |
|----------------------------|------------------|-------|---------|
| 1 st class unit | >771 sq. feet | 15 | 10 |
| 2 nd class unit | 520-770 sq. feet | 13 | 8 |
| 3 rd class unit | 375-519 sq. feet | 11 | 6 |
| 4 th class unit | <374 sq. feet | 9 | 4 |

The fees collected in 97/98 were Nu 17 482 for water supply and Nu 12 503 for garbage. The residents of Trongsa town, restaurants, shops and hotels paid a total of Nu 171 425 in 97/98, of which the urban land tax amounted to Nu 57 350.

7.3.2 Urban sanitation: present situation

Due to limited infiltration capacity and a larger consumption of water in the town, the sanitation system is insufficient. The sanitation facilities in Trongsa town vary from shared latrines to closed septic tanks. Most septic tanks within the urban area are without infiltration systems like soak pits, or the soak pits are not in function. This may result in wastewater entering the soil surface during the wet season, and problems like smell, spreading of diseases and bad water quality for irrigation may occur. When the septic tanks are filled up, the sewerage is manually moved and deposited in the closest stream. There are separate systems for grey water and sewerage in Trongsa town.

According to the Public Health Engineering Unit, a team from the World Bank visited Trongsa in 1998 to assess the need for upgrading of the water supply and sanitation facilities in the town. An appraisal mission will visit Trongsa in October 1998.

7.3.3 Impacts

Since the Mangdechhu River is not used as a source of drinking water or a primary recipient for wastewater, the project will have no direct impacts on the quality of water supply and sanitation facilities in Trongsa town. As an indirect impact of the project, more people are expected to settle down in Trongsa due to more activity and trade in the area. In that sense, adequate sources for drinking water and systems for sanitation will be needed. There is a definite need to improve the water supply and sanitation facilities in Trongsa town regardless if the Mangdechhu hydropower plant is realised or not.

7.3.4 Mitigation measures

The source for water supply needs to be changed from stream water to ground water to the extent possible. Utilisation of river water via infiltration through the riverbank may be a solution. Anyway, there is a need for chlorination in the intake tank if the water is to be used for drinking purposes.

In highly populated areas, the solution for proper sanitation seems to be a closed system with water closet and wastewater treatment. This is also recommended for Trongsa town which is expected to experience an increase in population during the next decades. The wastewater treatment plant needs to have both mechanical and biological treatment with following infiltration.

7.3.5 Costs

The Public Health Engineering Unit has estimated the costs to improve water supply in Trongsa town to about Nu 2 million. This will include a better source for intake, chlorination and an improved pipe system.

Without taking the costs for building a wastewater treatment plant into account, an improvement of the sanitation system in Trongsa town is estimated to about Nu 3-5 million.

In addition, there is also a need to improve the storm runoff system in Trongsa town, requiring investments in the order of Nu 3 million.

The total need for investments in the water supply and sanitation sector amounts to about Nu 10 million without treatment plant.

Currently water supply fees cover only a part of the operation and maintenance costs. Since the service level is not adequate, the willingness to pay fees is most likely low. At the same time, the ability to pay is expected to be low. To enhance the willingness to pay increased fees, improvements in water supply should be given priority in Trongsa town.

An investment in the order of Nu 10 million in the sector would require at least a ten-fold increase in fees just to cover operation and maintenance costs. Such an increase in fees seems impossible to implement in the short run. If the improvement should be financed by a loan, the fees have to increase even more to be able to service some of the debt. It can be concluded that the sector need to be subsidised within the foreseeable future.

7.4 Project camps

7.4.1 Temporary labour camps

Labourers who work during the construction of the Mangdechhu hydroelectric power plant will be located in temporary labour camps for shorter periods e.g. during building of roads and tunnels. These camps will probably be for labourers not bringing their families. However, even the temporary labour camps need to be provided with adequate water supply facilities to avoid health problems like waterborne diseases. Most likely, the drinking water still needs to be boiled if chlorination is not provided.

If the infiltration capacity is appropriate, soak pit latrines with slab are recommended. The capacity of one soak pit latrine is expected to be 20 persons per toilet i.e. a camp of 100 persons will need 5 toilets in a unit. Standardised design for such units has been developed in Bhutan.

The Public Health Engineering Unit in Trongsa will assist the contractors to design and construct both water supply and sanitation facilities.

Semi-permanent camps (5-10 years)

Labourers, who will stay in the project area during the whole construction period, will probably bring their families. This will require even better facilities regarding water supply and sanitation. More efforts need to be done to find good sources of water supply, preferably ground water.

Pour-flush latrines are recommended as sanitation system if the infiltration capacity in the ground is good enough. These pour-flush latrines with two tanks will compost the solid waste and the same tank

may be re-used. About 20 persons per unit are also expected to be the capacity of this sanitation system.

7.4.2 Permanent camps

The staff (and their families) who will operate the power plant will be located in a permanent camp/colony close to the power plant. For this permanent camp, the water supply and sanitation facilities need to be as adequate as recommended for Trongsa town due to the large number of people gathered in the colony. The water supply system needs to include preferably a ground water source, chlorination intake tank, pipe systems and water taps inside the houses.

The sanitation facilities are also recommended at the same level as for Trongsa town i.e. a closed system with treatment. This permanent camp will probably be located close to the Mangdechhu River, and the river will probably be used for several purposes like cloth washing and bathing. This will require sanitation facilities that do not infiltrate sewerage in the river bench to avoid contamination of bacteria.

7.4.3 Mitigation measures at the camps

The contractor should provide adequate water supply and sanitation systems in the various camps.

Maintenance of the water supply and sanitation systems and running of a relatively small wastewater treatment plant connected to the permanent camp/colony.

Monitoring of the bacteriological content in the drinking water on a regular basis in the various camps due to the high risk of waterborne diseases when many people live relatively close together.

Environmental awareness campaign to minimise the environmental health problem could be organised by NGOs or the local health administration in Trongsa. This is intended to encourage the people living in the camps to deal more effectively with environmental and health problems.

Strengthening preventive health care facilities.

Disposals of solid waste during the construction phase:

Separate pits for dumping bio-degradable and non-biodegradable wastes, the later must be taken out after the completion of the contractor's work. Papers and similar materials should be burnt occasionally.

Chemical waste management during the construction period:

Measures need to be taken to prevent dumping of chemical waste in the river or in any other water bodies. Chemical waste should be dumped in a certain place and treated occasionally in a proper way.

7.4.4 Costs

The costs to provide adequate water supply and sanitation facilities in the various camps, should be an integral part of the construction costs, and is therefore not included.

7.4.5 Monitoring plan

The drinking water need to be monitored on a regular basis both during the construction phase and afterwards in the permanent camps, especially analyses of coliform bacteria.

Monitoring of the river is described in section 10.

8 Aquatic Flora and Fauna

8.1 Introduction

In a river like Mangdechu, the fish population is depending on the amount and quality of bottom animals. The bottom animals on their side are eating attached algae and decomposing forest leaves. Change in water flow, water temperature and water quality may have great impact on the living conditions for many organism groups constituting the aquatic life.

8.2 Review of existing literature

No information exists on water flora and fauna in Mangdechu River.

8.3 Field work in Mangdechu 1998

8.3.1 Sampling stations

The same stations as for the water quality study were applied:

- Inlet of future reservoir
- Damsite
- Tailrace area

8.3.2 Description of the water habitats:

The two uppermost stations are situated in the canyon just downstream of Trongsa Town. There is heavy overhanging jungle on both sides of the river. The water flows in vigorous rapids with water velocity of approximately 1-3 m/s. The bottom consists of big to medium boulders.

In the tailrace station the river flows in very forceful rapids with an estimated water velocity from 2-5 m/s. The river-bed consists of big boulders and bare rocks. Along the shore a few more quiet backwaters could be found where biological samples could be collected.

8.3.3 Sampling of biological material

No macrophytes could be detected in the river. This applies to all sections.

Zooplankton was also judged to have no importance in this kind of turbulent river, and therefore omitted from the study.

Samples were collected from the following biological components:

- Green algae and mosses
- Diatom cover on stones
- Phytoplankton/drifting algae
- Bottom animals

Very little green algae could be seen on the stones. The diatom cover was infiltrated with silt material, indicating that the river in periods can have a relatively silty appearance. On some big stones and cliffs, mosses could be seen.

In the two uppermost stations leaves were found between the stones giving food for big stoneflies and other insects larvae. The over-hanging jungle is an important factor providing food for the bottom animals on this section of the river.

At the tailrace station there were no overhanging trees on either side of the river, only small bushes. No dead tree leaves were found between the stones. Visually judged during the sampling, the flora and fauna were poorer at this station than at the stations in the reservoir area. It should be noted that it was very difficult to sample bottom animals in the main stream of this river section, due to dangerous wild flow.

It seems clear that the river on the stretch between inlet of the future reservoir and the tailrace will have physical limitations for high biological production due to:

- High water velocity and wild rapids causing scouring effects on any vegetation establishment
- Low water temperature due to high-mountain snowmelt impact.

8.4 Results: Aquatic macrophytes

No aquatic macrophytes were observed in the river along the stretches that were visited. The strong and vigorous current, as well as water flow alterations makes the habitat too rough for rooted water vegetation.

8.5 Results: Phytoplankton

No phytoplankton species were found in the samples taken. This indicates that there are no slow flowing areas of Mangdechu River upstream of Trongsa. It also indicates that there are restricted possibilities to get a lake-like primary production in the reservoir, as there is no inoculum coming from upstream. Short water residence time in the reservoir will also be such a constraint.

8.6 Results: Periphyton

8.6.1 Degree of Coverage

Three categories of attached growth, here called periphyton, were collected:

- Green filamentous algae
- Mosses
- Diatom cover on stones (thin slippery algal cover that is dominated by diatoms)

Very little green filamentous algae could be seen on the stones. The diatom cover dominated and was infiltrated with silt material, indicating that the river in periods can have a relatively silty appearance. On some big stones and cliffs, mosses could be seen.

The thin, and slippery diatom cover appeared on all stones in the river, and constitutes the main primary producer group in Mangdechu, see Figure 8.1. Mosses and filamentous algae were rather rare. The high water velocity, vigorous rapids and alteration in water flow restrict the possibility for growth of other plants than the thin diatom cover on stones.

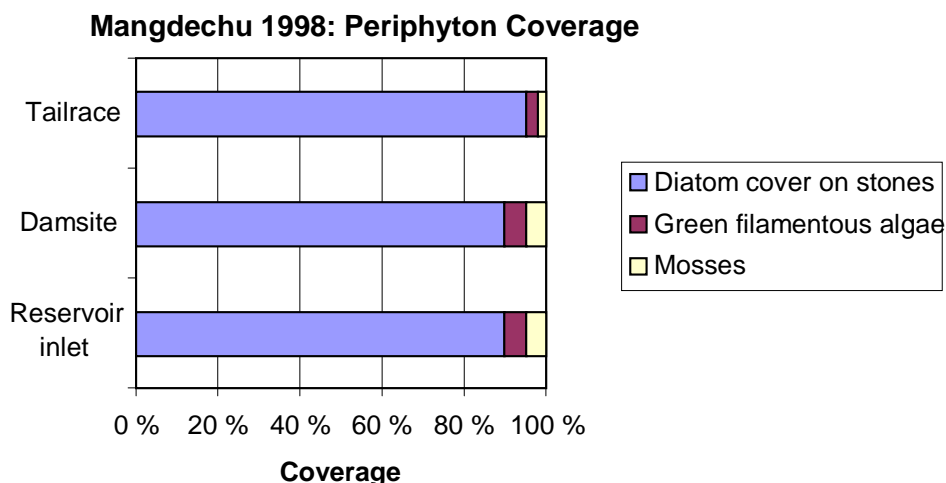


Figure 8.1 Approximate bottom coverage of the periphyton elements cited. Visually judged in the field.

8.6.2 Species composition

In Table 8.1 the species composition found in the periphyton samples are listed. The diatom group belonging to the thin slippery “Diatom cover” is most common, and is the most important primary producer group of Mangdechu River.

Table 8.1 Species composition and relative dominance of the periphyton samples collected from Mangdechu River 24-27th April 1998. x = observed, xx = common, xxx = very common, xxxx = dominating. NB: This reflects the relative abundance in the samples, not in the river. For abundance in the river, see text.

| Organism | Reservoir inlet | Damsite | Tailrace |
|---|-----------------|---------|----------|
| <u>Blue-green algae</u> | | | |
| <i>Phormidium sp. (6mm with calyptra)</i> | xxxx | xx | xxxx |
| Unidentified filamentous blue-green algae | | xx | |
| <u>Diatoms</u> | | | |
| <i>Ceratoneis arcus</i> | xx | xx | xx |
| <i>Cocconeis sp.</i> | x | x | x |
| <i>Cymbella ventricosa</i> | x | x | xx |
| <i>Cymbella spp.</i> | x | x | xx |
| <i>Diatoma mesodon</i> | | | x |
| <i>Didymosphenia geminata</i> | xx | xxx | xxxx |
| <i>Fragilaria ulna</i> | | x | |
| <i>Fragilaria spp.</i> | xx | x | xx |
| <i>Gomphonema spp.</i> | xx | xxx | |
| Unidentified diatoms | xxx | xxx | xxx |
| <u>Green algae</u> | | | |
| <i>Ulothrix zonata</i> | | xxxx | |
| <u>Mosses</u> | | | |
| Unidentified leaf mosses | xxxx | xxxx | |

8.7 Results: Bottom dwelling animals

Semi-quantitative samples were taken by stirring up the sediments (stones and gravel) of an area of about one square meter keeping a sieve-net funnel (mesh size 250 μm) downstream so that the animals that are stirred up will drift into the funnel.

The number of macroinvertebrates in each sample was significantly higher at the damsite compared to the other sites, see Figure 8.2. The total number of individuals at the damsite was about 1100 in each sample and about 3-400 at the reservoir inlet and at the tailrace. Also the number of macroinvertebrate taxa was higher at the damsite. Mayflies (Ephemeroptera) were the most common taxa at all sites. At the damsite caddisflies and chironomides were frequently observed as well. Stoneflies were only observed at the reservoir inlet and the damsite. Water beetle larvae were also observed only at these sites. Adult water beetles were observed at the damsite and the tailrace. The beetle larvae were dominated by *Elmidae* species, and the most common adult were the whirling beetles *Gyrinidae*. Oligochaeta were observed at all sites but most frequently at the damsite.

The diversity expressed as the total number of EPT-species (Ephemeroptera, Plecoptera, Trichoptera) were 18 at the damsite, and only 10 at the reservoir inlet and 7 at the tailrace, see Figure 8.3. The most common mayfly species were a *Baetidae*- species, whereas the most common stoneflies were *Isoperla spp.* and *Amphinemura spp.*. An *Agapetus* species were the most common caddisfly. Besides these species large specimen of *Dinocras* stoneflies were observed at the damsite and the reservoir inlet, as well as large specimen of a *Philopotamidae* caddisfly at Damside.

The diversity within the EPT groups as calculated by Shannon-Wiener diversity index, Figure 8.4, showed about the same relative differences between the sites as for the EPT index. The values were about 1.5, 2.0 and 0.5 at the reservoir inlet, damsite and tailrace respectively.

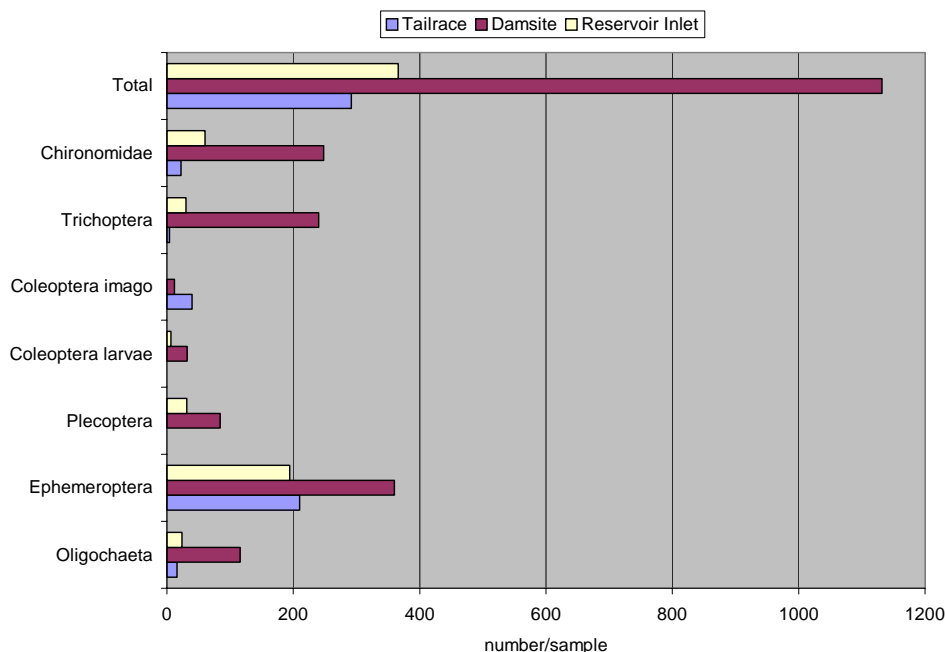


Figure 8.2 The number of individuals of selected macroinvertebrate taxa as observed in each sample at each site in the river Mangdechu 25.04.1998.

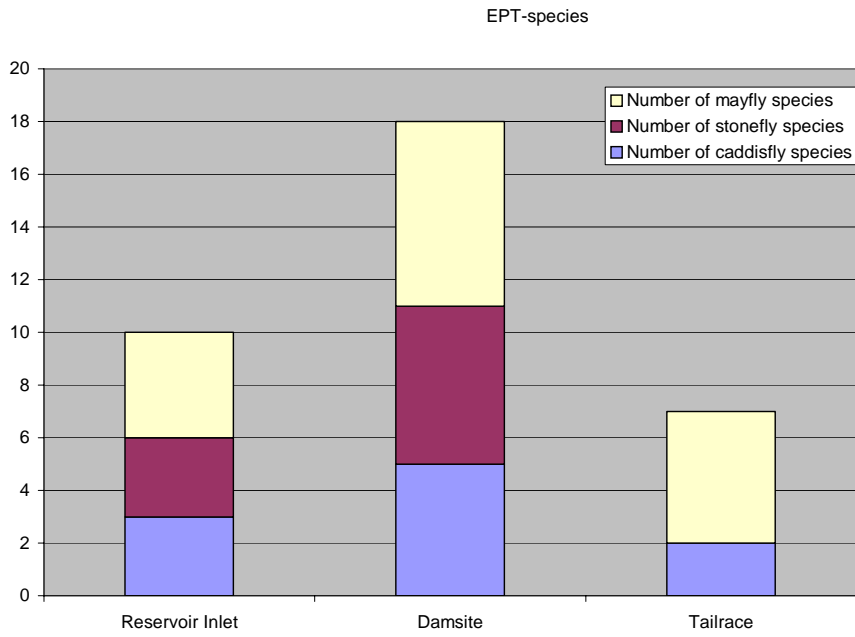


Figure 8.3 The number of species of mayflies, stoneflies and caddisflies (EPT; Ephemeroptera, Plecoptera, Trichoptera) observed at each site in the river Mangdechu 25.04.1998.

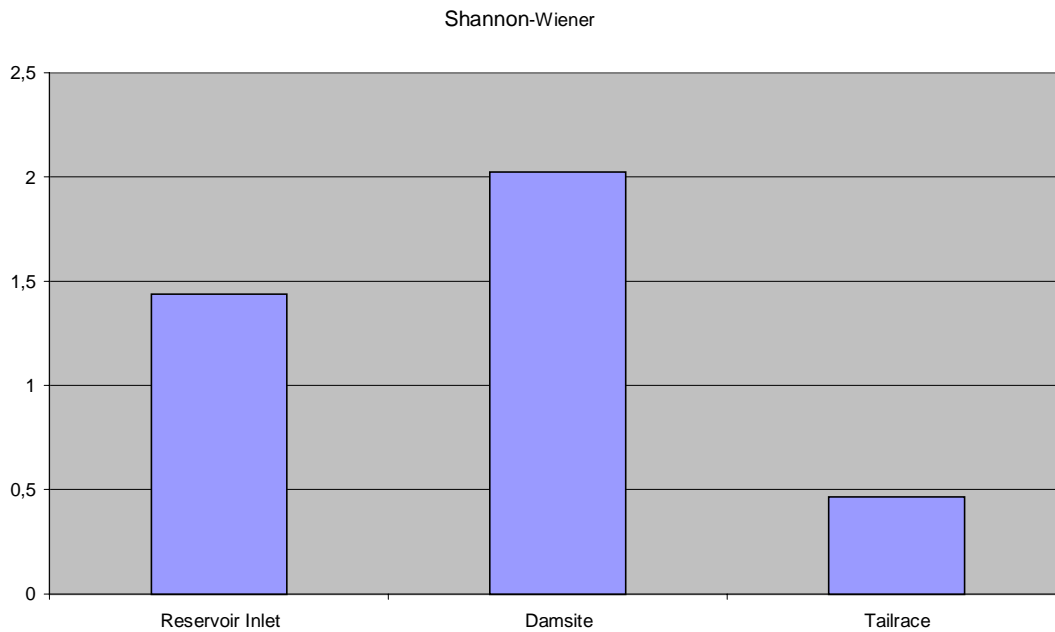


Figure 8.4 The diversity of mayflies+stoneflies+caddisflies expressed as Shannon-Wiener diversity index at each site in the river Mangdechu 25.04.1998.

8.8 Impacts on Aquatic Life

The greatest impacts on the biological life will occur in the low flow section downstream the dam. Here the area of productive riverbed will be reduced causing constraints for biological production. In the stretch from the dam down to Chendebjichu confluence the impact will be detrimental to normal river life if not a minimum release over the dam is established.

Further down in the low flow stretch increased influence of nutrient discharges may give higher specific water productivity in the area that remains. The water temperature will be higher in the low flow section improving conditions for some species and setting constraints for the development of others. Visible growth of attached algae will occur on the stones, but most likely not to an extent that will create esthetical or ecological problems. If so, a scheme of scouring floods can be established at a later stage.

In the reservoir area the river-bed will be transformed from rapids to a lake-like water body with strongly varying water level. Normally this reduces the conditions for aquatic life. To which degree the reservoir will be used for diurnal peaking el-production will be the major factor for estimating the biological impacts. In the prefeasibility report it was addressed that the possibility of fish cultivation in the reservoir should be elucidated. No planktonic species was found in the water of Mangdechu, which means that there will be little inoculum (seed-organisms) for establishing a lake-like production. Likewise the residence time of the reservoir will be very short, 4-5 hours. To establish lake like phytoplankton growth, the residence time need to be at least in the order of 4-5 days. As it is, in addition, reasonable to assume a peaking regulation scheme there is little scope for fish cultivation in the reservoir.

In the tailrace area the reaction of the water biota will depend very much on the way of running the power production. If the production will be stable the normal effect is an increase in the growth of attached algae and mosses downstream of power stations due to stable and high water flow. If the power production will be highly variable the opposite can happen. Attached growth will be scoured out. In the low flow period highly variation of the diurnal water flow can result in landing of fish and other moving animals if the changes occur too fast. To what degree the power plant is going to be used to cover peaking el-demand, is not clarified at this state of the technical planning.

Full utilization of peaking production will result in large water level- and water flow fluctuations. This will impose a stress to aquatic life and may be dangerous to people several kilometres downstream of the tailrace outlet. In dry periods the water flow just upstream tailrace will be only a few cubic meters per second (5-6 m³/s). Full peaking production will imply an on-off switching of 76 m³/s, a flow that will come and go rather suddenly. Fish and other organisms will be swept downstream, and may end in ponds or dry land during quick water withdrawal. A tailrace canal/magazine can dampen these quick water level alterations.

Increased erosion will also be a result of peaking el-production both in the reservoir and the tailrace area.

Water temperature during summer will be somewhat reduced downstream the tailrace canal as a result of reduced sun warming of the underground diverted water. This will impact both the primary producers as algae and mosses, but also the secondary producers will get reduced metabolism. Reduced grazing is often observed giving rise to nuisance periphyton growth. In the river stretch between the damsite and the tailrace the water will be warmer than it is today. This will increase the biological production per unit area, but since the river bed area will decrease, the overall biological production will decrease. However, it is not likely that the temperature changes will have any detrimental effects on river biology.

Super saturation of nitrogen and other gasses, if precautions are not taken, can cause damage for bottom dwelling animals and fish, see section 6.7.1.

The biology in the river may be affected by accidental discharges of fuel, oil and construction chemicals.

Quarries, tunnel blasting, spoil deposit storages, construction and adit roads will increase the erosion load to the river. This may sometimes cause large damage to fish and other river biota, particularly when discharged to clear water systems. As Mangdechu River are adapted to large variations in sediment load from the nature (suspended sediment content varies from 2-1200 mg/l), it is not anticipated that the extra particulate load will give rise to any great damage.

Blasting by use of ammonium nitrate gives high runoff of nitrate and ammonium. Combined with use of concrete, particularly the spray concrete type, in tunnel security work, gives very high pH (up to 13) in the tunnel water. This results in transforming ammonium into ammonia which in small recipients have been shown to cause fish kill.

9 Mitigating Measures

9.1 Short description of the different measures

Minimum release

A minimum release over the dam will be necessary to take care of some of the ecological values of the low flow stretch as well as water use interests (water supply for wildlife, and pasturing cows). This should be of the amount necessary to prevent the water from disappearing among the boulders and rocks, which constitute the river-bed. As there are approximately 50 m of loose materials underneath the riverbed, it is believed that the need for minimum water release is of the order 1,5-3m³/s. We propose that a suitable minimum release is tested out during the first years of regulation. Starting with 3 m³/s and reduces this until the limit where the water disappears among the stones. Under no circumstances the minimum release should not be set below 1 m³/s. The most important thing to take care of is that water should be available for wildlife and pasturing household animals during the dry period.

Threshold dams

Construction of threshold dams (boulder based) along the low flow stretch can partly compensate for the reduced bottom area that follows the flow reduction. It will, however, be very difficult to make such structures in this rough terrain. The cost of such structures will be too high compared with the gain having in mind the relative restricted user interest connected to this river stretch. Although a very common abatement measure in the minimum release stretch in hydropower development schemes, threshold dams are not recommended here.

Sanitary devices

Adequate sanitary devices must be developed for Trongsa town, the labour camp at the damsite, and the labour camp at the tailrace area, see section 7.

Fuel, oil, and chemical storage areas

At the damsite as well as at the tailrace, special areas should be made available for storing fuel, oil and construction chemicals. The area should be equipped with collection device in case of accidental large spillage. Tanking and maintenance of the machines should also take place in this area.

Location of the labour camp at the damsite

The effluent discharges from Trongsa town will reach Mangdechu River upstream of the intake dam. This implies that the pollution from the town will be transferred to the tailrace area, and will not affect the vulnerable water quality of the low flow section. A similar advantage could be gained by locating the labour camp upstream of the dam. This will allow possible leakage from the sanitary device to drain to the reservoir. In this way the water quality in the minimum release river stretch downstream the dam will be protected against possible discharges from the labour camp. If the labour camp will be removed completely after the construction period, the location of the camp is more flexible.

Prevention of formation of supersaturation of nitrogen

Precautions must be taken that air is not allowed to come into the diversion tunnel, i.e. the tunnel must be filled with water at any time. The intake opening must be properly submerged in the reservoir at all times. No extra intakes should be constructed along the diversion tunnel. The swinging chamber should be open. If these precautions are taken, the problem with N-supersaturation should not occur.

Prevention of erosion in the spoil deposit

The spoil rock deposit should be placed on dry land, not on the river bench in such a way that the river will be allowed to erode in the material. Brooks and storm flow runoff must be diverted around the dump and not be allowed to erode the dump.

Sedimentation and infiltration of tunnel water

Tunnel water (leakages from the rock, drilling water, flushing water etc.) should pass a sedimentation dam with at least 24 hours residence time and be infiltrated in the terrain or through the dump afterwards. A normal flow from tunnels under construction (leakage + process water) is in the order $20 \text{ l} \cdot \text{min}^{-1} 100\text{m}^{-1}$. This can be used for dimensioning the sedimentation basins.

Safety arrangements at the tailrace entrance

If the power station is run to cover peaking el-demand, there should be made security arrangements like warning signs, sound signals, and perhaps fences should be set up at strategic places, to prevent people from falling into a rapidly increasing river. If full peaking production is practised in the low flow periods, the rapid water flow alterations will make great damage to fish and other aquatic life many km downstream. A tailrace canal with some magazine capacity can dampen these quick water level alterations. This structures will be costly, and another way of accomplishing the same is to develop routines for a gradually start and stop of turbines, for example use 20 minutes to half an hour to perform a full stop/start.

9.2 Cost of mitigating measures

Many of the measures given here is of the awareness type that necessarily do not have to include extra costs, other are or is supposed to be natural parts of the civil construction works and taken care of in the detailed design. Therefore only a few measures are believed to give extra costs beyond what is already planned to be built into the project.

Table 9.1 Approximate costs for the mitigation measures necessary to take care of aquatic environment, water quality, worker's camp drinking water and sanitation.

| Measure | Comments | Cost (Nu) |
|---|---|---|
| Minimum release | 1.5-3 m ³ /s a minimum release of this magnitude is normally built into hydropower projects today to take care of the environment, and the measure is therefore not priced here. | Some energy loss |
| Camps Water supply and Sanitary devices | See section 7 | Included in civil construction |
| Trongsa water supply and sanitary rehab. | If not financed before project implementation then, partly financed by the project see section 7 | 10,000,000.- excluding treatment facilities |
| Fuel, oil, and chemical storage areas | Is performed in most large construction project today | Civil construction |
| Location of the labour camp at damsite | Some extra costs to ensure that the seepage from the camp drains to the dam and not to downstream areas. | This should be regarded as an awareness measure and should not include extra costs (Civil construction) |
| Prevention of formation of supersaturation of nitrogen | | This measure is an awareness item and it will not result in any extra costs (Detail design) |
| Sufficient drainage of spoil deposits to prevent erosion | This is normally required from the environmental authorities and extra cost is small | No extra costs |
| Sedimentation and infiltration of tunnel water | This is normally required for larger tunnel works and it will most likely be the case here as well. | Most likely built into the project. |
| Safety arrangements at the tailrace entrance and adequate operation strategy to prevent too rapid changes in the water flow, if full peaking in the low flow season | | Some energy loss |

10 Monitoring plan

10.1 Laboratories

It is assumed that the analytical facilities are available in Bhutan. The samples have, however, to be sent to different laboratories to be able to cover all the parameters. The available laboratories are:

- The Soil and Plant Laboratory Simtokha, Ministry of Agriculture
- City Corporation Laboratory, Thimphu
- City Corporation Laboratory, Phuntcholing
- Penden Cement Authority, Samtse
- Division of Geology and Mines, Ministry of Trade and Industry, Thimphu
- Public Health Laboratory, Thimphu, Trongsa

10.2 Construction period

10.2.1 Mangdechu

3 stations should be monitored during the construction period:

Inlet of future reservoir
Downstream of the damsite
Downstream of the tailrace

The parameters should be: Temperature, pH, Turbidity, TOC, Faecal Coliform bacteria, suspended solids, Total -P, Total-N, Nitrate, Ammonium.

Observation frequency should be once a month.

10.2.2 Tunnel water

At each site where tunnel water is discharged, likely at damsite, main adit, power house / tailrace adit, the tunnel water should be monitored with sampling once a month for the following parameters:

pH, turbidity, suspended sediments, TOC, oil, total nitrogen, ammonium.

Discharges should be kept within the Bhutanese guidelines.

10.2.3 Primary recipient for spoil deposits

Drainage water from spoil deposits should be monitored with sampling once a month for the following parameters: pH, turbidity, suspended sediments, TOC, oil, total nitrogen, ammonium.

Discharges should be kept within the Bhutanese guidelines.

10.2.4 Areas for fuel, chemical, and machine storage/repair

Drainage from these areas should be monitored with sampling once a month for: pH, turbidity, suspended sediments, TOC, oil, total nitrogen, ammonium, and remains of actual chemicals.

Discharges should be kept within the Bhutanese guidelines.

10.2.5 Labour camp drinking water supply

See section 7.

10.2.6 Labour camp sanitary discharges

Discharges from the labour camps sanitary facilities should be monitored with sampling once a month (piped discharges, visible seepage, primary brooks or streams downstream of the sanitary devices). The parameters should be: Faecal coliform bacteria, pH, total-P, total-N, TOC.

Discharges should be kept within the Bhutanese guidelines.

10.2.7 Cost estimate for construction period monitoring

The project will have an Environmental Unit and their personnel will perform the sampling as part of their job. It is normally the rule/or custom in Bhutan that Governmental projects do not pay for analysis. The Environmental Unit will also take care of the reporting, and can initiate necessary actions if the monitoring results should indicate that this is needed.

The costs confined with the construction period monitoring will be negligible, only some bus-transport of samples and some chemicals and glassware.

10.3 Monitoring Plan for the Operation Period

10.3.1 Mangdechu River

Each year in late April a survey of bottom dwelling animals and periphyton should be performed at the stations

1. Inlet of the reservoir
2. Just downstream of the dam
3. Just upstream of Chendebjichu confluence
4. Just upstream of tailrace entrance
5. Just downstream of tailrace entrance
6. 5 km downstream of tailrace entrance

This is a period when the insect larvae are big and easy to detect, but before most of them have hatched to adult flying insects. One single sampling will give an integrated picture of the living conditions for the animals during the previous half year.

The results will give a good indication on to what degree the regulation scheme is disturbing the aquatic ecosystem. In this way the simple monitoring will be a good basis for adjusting the mitigation measures in the future.

At the same survey in April (i.e. once a year) water samples are taken on the same stations. These are analysed for the following parameters: Temperature, pH, turbidity, conductivity, colour, TOC, Ca, Mg, Na, Ca, Cl, SO₄, alkalinity, Total-P, Total-N, NO₃, suspended sediments, Fe, and Mn.

Local persons have to be trained.

10.3.2 Labour and operation staff camps

Drinking water supply for these camps should be monitored on a weekly basis for faecal coliform bacteria. If necessary, pollution abatement measures should be taken.

Discharges and seepage from sanitary systems should be monitored on a monthly basis for the following parameters: Faecal coliform bacteria, pH, total-P, total-N, TOC.

10.3.3 Cost of post construction monitoring programme

Training of staff will be performed during the construction period as part of the development project. It is assumed that this staff can continue the post construction monitoring, and that analyses still can be performed free of charge (Governmental projects). Thus, the monitoring costs will be negligible.

11 Consultations and literature

11.1 Consultations

The following institutions has be visited and consulted:

- Division of Power, Main Office
- Division of Power, Sediment Lab Unit
- Division of Power, Meteorological Unit
- Public Health Laboratory Thimphu
- Soil and Plant Laboratory Simtokha, Ministry of Agriculture
- Meeting with dr. Damber Kumar Nirkola, District Medical Officer, at Trongsa Hospital
- The Lab at the Hospital of Trongsa
- Meeting with the District Engineer of Trongsa, Mr. Phuentcho Dorji.
- DANIDA, Thimphu Office.
- Jimba Consultancy Services Ltd, Thimphu

11.2 Literature

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Ministry of Health and Education 1998. Public Health Engineering Unit, Health Division. Rural Water
Supply Programme. Project Standardisation Manual. Revised July 1998.

12 Appendix – Primary data referred to in text

Table 12.1 Water quality of Mangdechu. Values from April represent dry season, and values from June represent rainy season.

| Unit | Reservoir Inlet | | Damsite | | Tailrace | |
|-------------------------------|-----------------|----------|------------|----------|------------|----------|
| | 24-27.4.98 | 30.06.98 | 24-27.4.98 | 30.06.98 | 24-27.4.98 | 30.06.98 |
| pH | 7,39 | 7,33 | 7,39 | 7,35 | 7,43 | 7,45 |
| Conductivity mS/m | 4,43 | 4,19 | 4,39 | 3,90 | 4,85 | 4,97 |
| Alkalinity mmol/l | 0,41 | 0,40 | 0,42 | 0,38 | 0,50 | 0,48 |
| Turbidity FTU | 1,70 | 41,00 | 1,70 | 120,00 | 1,40 | 87,00 |
| Colour mgPt/l | 19,20 | 30,90 | 19,40 | 34,00 | 18,20 | 31,90 |
| Total Phosphorus ugP/l | 6,00 | 150,00 | 5,00 | 102,00 | 6,00 | 56,00 |
| Total nitrogen ugN/l | 285,00 | 330,00 | 255,00 | 235,00 | 250,00 | 250,00 |
| Nitrate ugN/l | 180,00 | 205,00 | 200,00 | 128,00 | 140,00 | 142,00 |
| Suspended solids mg/l | | 284 | | 378 | | 168,00 |
| Suspended inorg. Solids mg/l | | 278 | | 374 | | 156,00 |
| Tot. Org. Carbon mgC/l | 2,20 | 3,00 | 2,00 | 3,20 | 2,20 | 3,20 |
| Chloride mgCl/l | 0,40 | 0,20 | 0,40 | 0,20 | 0,30 | 0,20 |
| Sulphate mgSO ₄ /l | 1,70 | 1,10 | 1,70 | 1,00 | 2,10 | 1,30 |
| Calcium mgCa/l | 6,63 | 7,15 | 6,67 | 6,68 | 8,06 | 8,30 |
| Potassium mgK/l | 0,36 | 1,43 | 0,37 | 0,84 | 0,48 | 0,66 |
| Magnesium mgMg/l | 0,85 | 2,49 | 0,85 | 2,11 | 0,95 | 1,34 |
| Sodium mgNa/l | 1,19 | 0,88 | 1,19 | 0,74 | 1,20 | 0,59 |

Table 12.2 Mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) at 3 sites in the river Mangde Chu 25.04.1998. Method: stirring approximately 1 m² of the substrate by hand, handnet with mesh size 250 µm.

| | Reservoir Inlet | Damsite | Tailrace |
|---------------------------|-----------------|---------|----------|
| Ephemeroptera | | | |
| Baetidae 1 (niger type) | | 38 | 6 |
| Baetidae 2 (rhodani type) | 150 | 244 | 194 |
| Heptagenia | 11 | 8 | 2 |
| Rhithrogena | | 16 | 2 |
| Leptophlebiae | 19 | 60 | |
| Ephemerella 1 | | 4 | |
| Ephemerella 2 | 3 | 20 | |
| Indet. | | | 6 |
| <i>Number of species</i> | 4 | 7 | 5 |
| Plecoptera | | | |
| Dinocras 1 | | 4 | |
| Dinocras 2 | 6 | 4 | |
| Isoperla | | 36 | |
| Siphonoperla | 6 | 16 | |
| Amphinemura sp. | 19 | 20 | |
| Nemoura | | 4 | |
| <i>Number of species</i> | 3 | 6 | 0 |
| Trichoptera | | | |
| Agapetus -type | 19 | 196 | 2 |
| Philopotamidae | | 16 | |
| Hydropsyche sp. | | 8 | |
| Brachycentridae | | 16 | |
| Limnephilidae indet. | 3 | | 2 |
| Trich. indet | 8 | 4 | |
| <i>Number of species</i> | 3 | 5 | 2 |

Table 12.3 Benthic macroinvertebrates at 3 sites in the river Mangde Chu 25.04.1998. Method: stirring approximately 1 m² of the substrate by hand, handnet with mesh size 250 µm.

| | Reservoir Inlet | Damsite | Tailrace |
|---------------------|-----------------|-------------|------------|
| Oligochaeta | 24 | 116 | 16 |
| Gastropoda | 3 | | |
| Hydracarina | | 12 | |
| Ostracoda | 3 | | |
| Ephemeroptera | 194 | 360 | 210 |
| Plecoptera | 31 | 84 | |
| Coleoptera larver | | | |
| Elmidae | 6 | 20 | |
| Gyrinidae | | 4 | |
| Indet. | | 8 | |
| Coleoptera imago | | | |
| Gyrinidae | | | 36 |
| Indet. | | 12 | 4 |
| Trichoptera | 30 | 240 | 4 |
| Simuliidae | 6 | 4 | |
| Chironomidae larvae | 60 | 248 | 22 |
| Chironomidae pupae | 6 | | |
| Other diptera | 3 | 24 | |
| Total | 366 | 1132 | 292 |

Table 12.4 Recommended Criterias for Drinking Water and Raw Water Supplies in Bhutan³

Maximum acceptable concentration for drinking water and raw water

| Parameter | Drinking water ⁴ | Raw water ⁵ |
|------------------------|-----------------------------|------------------------|
| Pesticides (total) | 0.1 mg/L | |
| Colour | 15 TCU | |
| Temperature | 15°C | |
| Turbidity | 10 NTU | 75 NTU |
| pH | | 6.5-8.5 |
| Nitrate | | 45 mg/L |
| Total dissolved solids | | 500 mg/L |
| | | |
| | | |
| | | |

³ Bhutan: recommended by the National Environmental Commission until more relevant information becomes available.⁴ Drinking water guideline apply to “treated” or “finished” water as it comes from the tap, and are not intended to be applied directly to surface waters.⁵ Raw water supplies refer to waters that are used as the intake source for public use and can include surface water and ground water.

Table 12.5 Bacteriological drinking water quality criteria developed by WHO⁶

| Treatment level and usage | Guideline value |
|---|---|
| All water intended for drinking: E.coli of thermotolerant coliform bacteria | Must not be detectable in any 100 ml sample |
| Treated water entering the distribution system: E.coli of thermotolerant coliform bacteria Total coliform bacteria | Must not be detectable in any 100 ml sample Must not be detectable in any 100 ml sample |
| Treated water in the distribution system: E.coli of thermotolerant coliform bacteria Total coliform bacteria | Must not be detectable in any 100 ml sample Must not be detectable in any 100 ml sample. In the case of large supplies, where sufficient samples are examined, must not be present in 95 % of samples taken throughout any 12 month period. |

¹ Bhutan: recommended by the National Environmental Commission until more relevant information becomes available.

¹ Drinking water guideline apply to “treated” or “finished” water as it comes from the tap, and are not intended to be applied directly to surface waters.

¹ Raw water supplies refer to waters that are used as the intake source for public use and can include surface water and ground water.

¹ WHO:

⁶ WHO: Sjä appendix-Dag har denne