Appendix E: Final Report

ESSA 35 YEARS

Environmental Flows Assessment

Upper Trishuli-1 Hydropower Project, Nepal

Prepared for:

NWEDC NEPAL WATER & ENERGY DEVELOPMENT COMPANY

IFC International Finance Corporation World Bank Group

Appendix E:
Environmental Flows Assessment

Supplemental ESIA-

Upper Trishuli-1 Hydropower Project, Nepal

November 2014

Prepared for:
Nepal Water and Energy Development Company
&
the International Finance Corporation (IFC)

Cover Photo:
Trishuli River downstream from the proposed powerhouse site, facing upstream. October, 2013. [Photo: P. de la Cueva]

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1 Overview

ESSA Technologies Ltd (ESSA) is acting as Independent Environmental and Social Consultant to provide support and guide the environmental and social management of the Upper Trishuli-1 (UT-1) Hydropower Project in conformance with international standards. This report presents an assessment of the potential impacts that the operation of the UT-1 Project could have on the aquatic habitats within the Project's area of influence.

The UT-1 is a 216 MW greenfield hydropower project which will be located in the Rasuwa District in Central Nepal. The project consists of a 77 m wide concrete gravity dam which stands 30 m from the ground and has a 26.3 m deep concrete foundation. The UT-1 is designed to function as a run-of-river facility, working constantly up to a maximum diversion capacity of 76 m^3/s. The diverted water will be transported by a 9.82 km headrace tunnel to an underground power station where three 72 MW Francis turbines will be installed. At the normal operating level (1255 m), the reservoir area will occupy 2.1 ha.

The Trishuli is a perennial snow and rain-fed river with a marked seasonality in its hydrology due to the monsoon rains. Mean flows at the proposed intake site vary from 39 m^3/s in February and March to a maximum of 558 m^3/s in August, at the peak of the monsoon. Once in operation, the UT-1 Project will create a flow-reduced[1] segment of roughly 11 km along the diversion reach; from the intake site to the tailrace. According to the currently proposed operational rules, a minimum of 10% of the mean monthly flow (consistent with Nepal regulatory requirements) will be released as environmental flow.

Under the proposed flow management scenario, and based on the mean monthly flows at the intake site, 10% of the mean monthly flow would be released into the diversion reach from November to April, resulting in environmental flows (see Table 5-2) ranging from 3.9 m^3/s (months of February and March) to 8 m^3/s (November). The rest of year higher flows (ranging from 13% in May to 86% in August) will be released to the diversion reach.

The potential impacts on the aquatic habitats due to flow alteration in the diversion reach were not evaluated as part of the original Environmental Impact Assessment (Jade Consult 2011). This assessment provides the basis for the development of an Environmental Flows Management Plan that will mitigate potential impacts of reduced flows on aquatic habitats.

In terms of potential social impacts, a number of water uses (i.e. domestic/recreational, irrigation and water mills) have been identified in the lower part of the diversion reach. It has also been confirmed that non-commercial fishing is practiced in the area around the powerhouse. Fishing activity is very limited in the Project's area and mostly restricted to

[1] See Section 5.2 for details of the operational design.

recreational purposes although two families are reported to be dependent on fishing for their livelihoods.

In order to assess the potential impacts of the alteration of the natural hydrological regime (see Section 2 for details on the hydrological analysis), and evaluate the adequacy of the proposed environmental flow operational rule, this report has applied a hydrology-based assessment methodology that takes into account the existing knowledge about the ecology of the aquatic habitats in the Project's area of influence.

In a first step of the adopted methodological approach, the potential impacts of the hydrological alteration associated to the UT-1 Project have been identified using a streamlined Impact Hypothesis Framework (Section 3). This framework allows identifying key habitat and ecosystem components and processes that could be potentially affected by the Project. The barrier effect of the dam on fish migration, the effects of changes to flow patterns in the diversion reach, and potential fish entrainment at the intake, are the three impact hypotheses which were considered most likely for the UT-1 Project.

The snow trout species *Schizothorax richardsonii* was selected as the key indicator species for this assessment. *S. richardsonii*, locally known as *Buche Asla*, is a mid-range migratory species identified as vulnerable by the IUCN Red List[2] and is the only fish species consistently found to occur in the Project area. According to available literature, *S. richardsonii* is believed to spawn in two distinct periods: (i) at the start of the monsoon season in March-April, coinciding with upstream migration; and (ii) at the end of this season in October-November, coinciding with downstream migration. This species could be affected by the three identified impacts and its ecology and life cycle is representative of other cold-water species in the Himalayas.

During the 2013-2014 aquatic baseline survey, field observation of female gonads of the captured specimens of *Schizothorax richardsonii* showed presence of ovaries with mature eggs starting from July to February. No eggs were found during the months of March and April and immature ova were observed in the months of May and June. These observations suggest that spawning in the project area occurs from March to May, before the monsoon season. However, a single monitoring year does not provide enough data to accurately define the spawning periods.

Our analysis concludes, based on the available data, that: (i) an environmental flow release of 10% of the mean monthly flow during May to February is likely sufficient for in-stream ecological needs; and (ii) ***increased instream flows*** (greater than 10% of the historical range) ***are recommended as an interim environmental flow regime for the critical March-April, when upstream migration and spawning occur,***. The final environmental flow regime (i.e. timing and quantity of flow to be released in the diversion reach) to be

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[2] http://www.iucnredlist.org/info/terms-of-use

adopted during operations will have to be defined in an adaptive way as critical knowledge gaps on the ecology of *S. richardsonii* are addressed by gathering additional aquatic baseline data[3].

The potential impacts on power generation of releasing increased flows during the critical period of March-April were evaluated (see Section 5) through a sensitivity analysis. In the absence of sufficient eco-hydrological information, three environmental flow scenarios were tested for the March-April period to frame the analysis and determine the range of potential impacts on power generation; release of 80% (a generic conservative scenario representing a presumptive flow standard, Richter *et al.* 2012, for cases with high uncertainty and lack of information), 50% and 10% (currently proposed scenario) of the mean monthly flow.

The sensitivity analysis concluded that annual power production will be reduced by about 5% for each month (March and April) in which the most conservative (80%) environmental flow is maintained, which would have a significant impact on the economic viability of the Project. If technically feasible, it is recommended that required maintenance of the power generating infrastructure occur during March and April to help offset the economic impacts of environmental flow releases.

To address the potential impacts of the project on the local aquatic habitats and to guarantee the viability of the local population of snow trout, in accordance with IFC's Performance Standard 6, outstanding key aquatic knowledge gaps must be filled. This report recommends (Sections 6 and 7) that the following next steps should be undertaken:

i. Develop an <u>Environmental Flow Management Plan (EFMP)</u> to address the ecological knowledge gaps and maintain viable fish populations during operations. Once additional ecological data is collected the final environmental flow rules should be determined and incorporated in the EFMP. Section 7 of the report describes a proposed terms of reference of the EFMP.

ii. Assess and implement adequate <u>mitigation options for impacts on aquatic habitats.</u> Three types of impacts have been identified as likely for the UT-1 Project: the barrier effect created by the dam, the risk of entrainment in the penstock, and the alteration of the hydrological regime in the diversion reach. The following mitigation measures are required to help maintain a viable population of *S. richarsonii* in the diversion reach: release of environmental flows, maintenance of spawning grounds, and fish screens at the intake. Depending on the results of additional aquatic baseline monitoring additional measures may also be required to mitigate the barrier effect such as coordinated actions (e.g. joint fish stocking programs) with other hydropower sponsors and relevant stakeholders.

[3] See Section 7.3 for the complementary aquatic baseline surveys proposed as part of the Environmental Flows Management Plan

2 Hydrology and Water Resources Use in the Project Area

2.1 Hydrological analysis

The Trishuli River arises in the Tibetan Autonomous Region of China and includes a watershed area of 4,351 km^2 upstream of the site of the headwater works for the proposed UT-1 power generation station. Flow is derived from a mixture of seasonal monsoon precipitation and meltwater from snow and ice at higher elevations. Of the total catchment, above 60% is located in Tibet Autonomous Region of Peoples Republic of China, while less than 40% lies within Nepal. Above 93% of the catchment area lies above 3000m.

About 80% of annual precipitation falls during the June-October monsoon, with episodes of very high precipitation and discharge. Between-year climatic variation results in up to two-fold differences (Figure 2-1) in average discharge over the 44-year period of the historical record (1967-2010). In addition to the historical record, some forward looking studies (Bajracharya *et al.* 2011) have considered how climate change will affect flow regimes, as glaciers continue to decline in some parts of the region and monsoon patterns may become altered. These considerations are currently beyond the scope of this study, although our methodology could easily be applied to analyze hypothetical future scenarios.

Hydrographic data for the present study are based on a 44 year record of continuous daily observations made at Betrawati (Gauge Station 447, Nepal Department of Hydrology and Meteorology) located 14 km downstream of the proposed UT-1 powerhouse. This record was provided through the courtesy of NWEDC, and is consistent with the data reported in the Hydrological Analysis Chapter of the Daelim Kyeryong (2011a) Basic Design Report. To create a synthetic daily hydrograph at the UT-1 intake, Betrawati gauge data are adjusted downward by a factor of 0.8971 to account for the slightly smaller watershed area upstream from the gauge. The daily hydrographs (Figure 2-2) show the extent of variation in daily discharge for representative low-flow (1970) and high-flow (2000) years.

Potential effects of climate change on flows in the Trishuli River have not been considered in the design of the UT-1 Project. A recent trend analysis (Bajracharya *et al.* 2011) determined that mean flow during the dry season is decreasing at a very slow rate, whereas there is no clear trend for mean annual flows. An increasing trend for maximum flows, with high variability, was also been observed. These trends could reflect that the glacier contribution at the dry season is becoming less over time while the rain contribution during the wet season is not uniform.

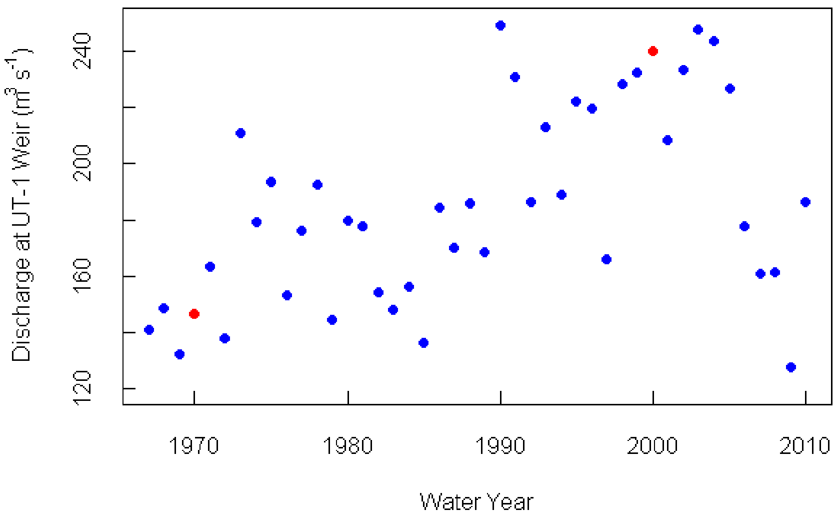


Figure 2-1: Unimpaired average annual discharge for the Trishuli River at the UT-1 intake weir based on scaled Betrawati gauge data for 1967–2010. Representative low-flow (1970) and high-flow (2000) years are highlighted with red symbols. The water year period is based on the interval from March 1 to the last day of February in the following calendar year.

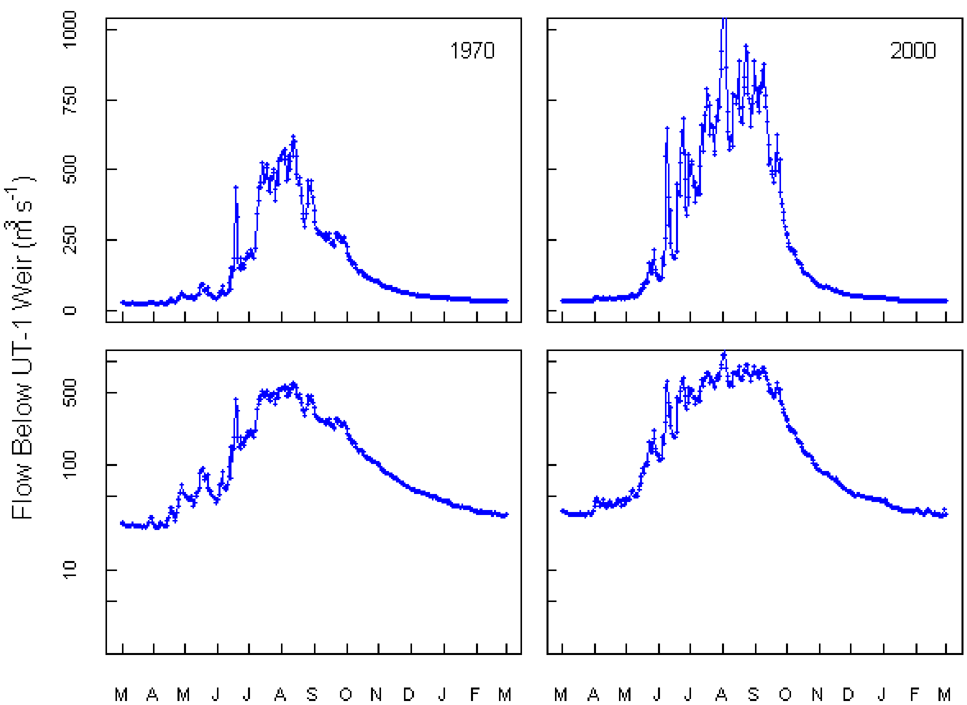


Figure 2-2: Daily flow hydrographs for representative low-flow (1970) and high-flow (2000) years in linear (upper) and logarithmic (lower) scales.

2.2 Water and river users

In terms of river/water users in the Project area, Nepal Environmental and Scientific Services (NESS) has recently (August 2013) conducted a river users inventory as part of the complementary environmental and social baseline, and identified a number of river and water uses along the 11 km diversion reach of the Upper Trishuli-1. These uses are concentrated on the lower part of the diversion reach (see Figure 2-3 for approximate locations) and include: (i) two traditional watermills (*ghatta*) which are used throughout the year for grain grinding and are supplied with water from the Trishuli by earthen canals; (ii) an area of irrigated agricultural land of approximately 0.2 hectares where rice is grown during the monsoon season; (iii) a stretch of the river used by inhabitants of Gunchet settlement for domestic purposes (drinking, bathing, etc.) during the dry season; and (iv) non-commercial fishing is practiced, particularly during the fish migration periods of the monsoon season, by local fishermen in the lower part of the diversion reach and around the powerhouse area.

Figure 2-3: River uses in the diversion reach of the Project.

As for other river uses in the diversion reach, it should be noted that rafting is not practiced in the area, due to the difficult access and rugged topography, and no cremation or other religious sites were identified during the survey for water users. Local communities in the Project area are predominantly non-Hindu and the only known religious use of the Trishuli River in the region takes place in Betrawati, about 14 km downstream of the powerhouse.

The social baseline survey (see Appendix A of the Supplemental EIA, ESSA 2014) has found that fishing is practiced for non-commercial, livelihood-complementary purposes in a stretch of the river upstream of the tailrace. The usual method for fishing is setting traps during the monsoon period when fish migration takes place.

Fishing activity was also recorded as part of the aquatic and fish surveys conducted by NESS through August 2013-July 2014. Fishing is practically non-existent in the upper reaches of the studied river reach (see Appendix B for detailed aquatic survey results), due to the steep terrain and the difficulty in accessing the river in that part, as well as the restrictions on fishing imposed by the Langtang National Park (eastern bank of the Trishuli). In the lower river reaches, however, fishing is practiced occasionally by local communities. The number of fishermen reported by NESS aquatic survey field team is shown in Figure 2-4.

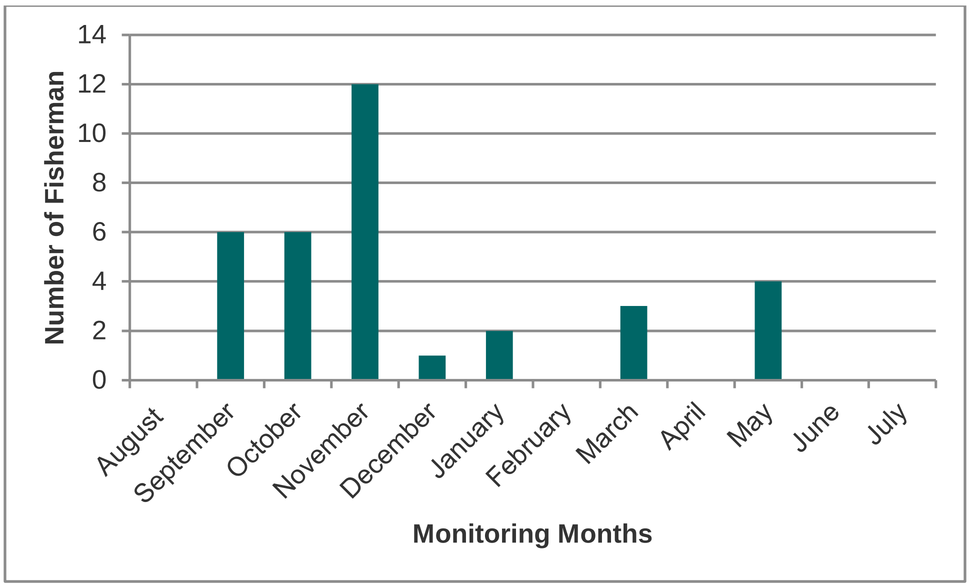


Figure 2-4: Fishing activity registered by NESS field team through the aquatic survey period (August 2013-July 2014)

Only two fishermen reported their livelihoods depending on fishing activities. The other fishermen practice fishing for recreational purposes.

At the watershed level, the major water user is hydropower generation, which has been rapidly developing in the last years. As of November 2013, there were 5 hydropower projects in operation, 9 under construction or under granted construction license (including the UT-1 Project), and another 19 have a survey license. All these facilities are run-of-river type with generation capacities ranging from 1 to 216 MW. Aquatic habitats in the watershed have therefore already been impacted and fragmented by the current level of development. Existing and under construction weirs will act as barriers for fish migration. Unless effective mitigation options are implemented, the upstream movement of fish into the UT-1 Project’s area of influence is blocked by the hydropower facilities Trishuli 3A and 3B, currently under construction (see Figure 2-5). The mitigation of cumulative impacts on aquatic ecology by multiple hydropower projects will require coordinated action among hydropower sponsors (see Section 7.7).

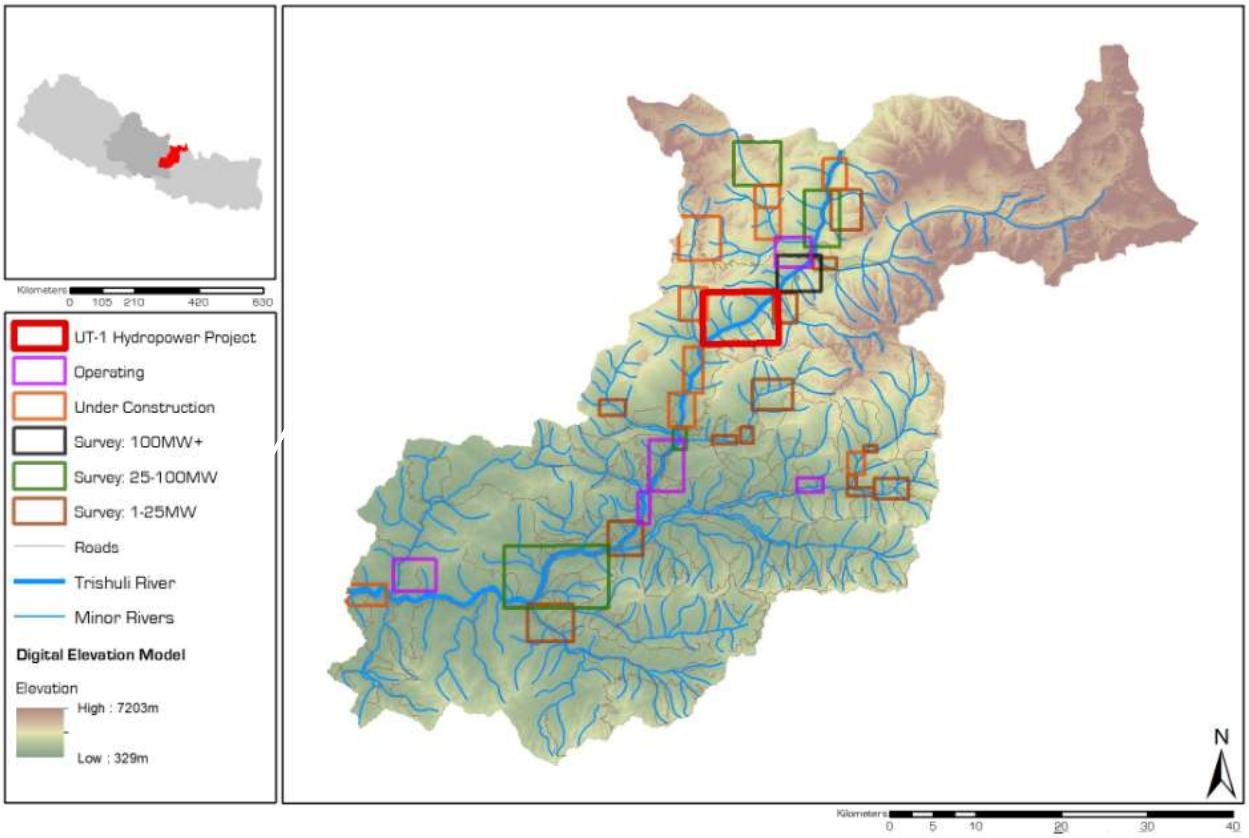


Figure 2-5: Hydropower development (existing and under planning) in the Trishuli Watershed

3 Impact Hypotheses and Linkages to Habitat

3.1 Introduction

As with any other run-of-river hydropower facility (Figure 3-1), the construction and operation of the UT-1 Project has the potential to create impacts within the diversion reach, as well as upstream of the weir and downstream from the tailrace. The severity and magnitude of the impacts will depend on the details of the Project's design, as well as the local hydrology and aquatic ecology.

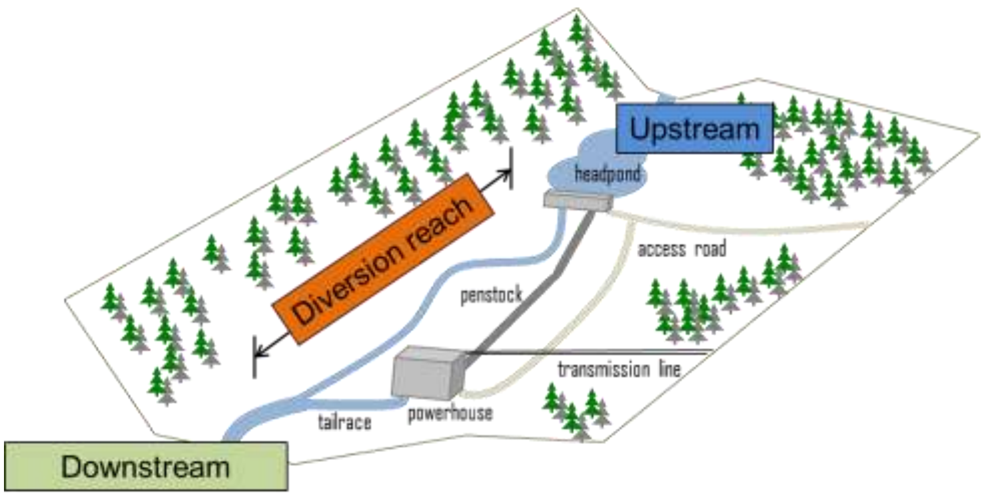


Figure 3-1: Schematic representation of a run-of-river facility showing the three distinct sections: upstream, diversion and downstream.

The potential impacts associated with the UT-1 Project were identified using an *impact hypothesis* (or *pathways of effect*) approach, which defines a set of potential impact pathways (as described in the following sections) that could be caused by the project, including barriers to migration, mortality due to entrainment in the penstock, changes in habitat, alteration of the natural hydrograph, movement of sediment and organic material (primarily wood), and loss of habitat connectivity. ESSA has been successfully applying the impact hypothesis approach for the analysis of fisheries and water resources issues for more than 30 years of (Connors *et al*. 2014, Greig *et al.* 1992). Formal validation of impact hypotheses requires pre- and post-operational monitoring data. At this stage of the UT-1 Project, the impact hypothesis approach is therefore used to frame the assessment, identify potential impact pathways and the ecosystem processes/components and key species most likely to be affected.

The following sections describe the impact hypotheses that have been considered in the analysis. The likeliness of these hypotheses has been qualitatively established based on the characteristics of the UT-1 Project and the available information on the local aquatic ecosystems (see Section 4) for more information on fish species in the Trishuli).

3.2 Upstream Hypotheses

a. Construction of the weir will lead to loss of river habitat and the creation of lake-type habitat.

The weir will create a 2.1 ha reservoir to provide stable hydraulic conditions for power production. Pond area and retention characteristics will depend on flow, but may favor more lentic species over lotic species.

In hydroelectric developments which incorporate large reservoirs there are valid concerns about effects from thermal stratification in the upstream pool, in addition to concerns about oxygen deprivation in stratified deep waters (Gubhaju 2002). Those issues should be of less concern for the proposed UT-1 development, since the design includes a relatively small impoundment which will provide a short-term storage buffer to insure a smooth and continuous water supply to the turbines. Mean residence time behind the upstream weir is therefore expected to be brief at most times of the year.

While a reservoir will be created, the hypothesis is considered to be **unlikely** due to the relatively reduced size of the reservoir, the absence of lake-favoring species in this part of the Trishuli River, and the existence of a barrier to their natural dispersal.

b. ***The weir will impair the movement of fish upstream of the structure, resulting in a barrier effect for upstream migration and potential changes in composition and abundance of species upstream/downstream of the weir.***

This hypothesis is considered **very likely**. With a steep chute and vertical change of about 8 meters, the weir will almost certainly create an impassable barrier for natural upstream migration or dispersal.

c. ***Fish will be entrained in the penstock and / or stranded in the spillway, resulting in the impairment of downstream migration and potential changes in composition and abundance of species upstream/downstream of the weir.***

This hypothesis is considered **likely**, especially if no fish rack or similar device is used at the intake to mitigate the entrainment risk.

3.3 Diversion Reach Hypotheses

a. Construction of the weir will change the timing and magnitude of gravel and sediment recruitment to the diversion reach.

Although timing of sediment recruitment may change, this hypothesis is considered to be **unlikely** due to (a) the regular maintenance removal of sediment accumulating in the head pond, as well as periodical flushing of the sediments retained in the de-sand basins in the penstock, and (b) the contribution of high monsoon flow to the maintenance of existing geomorphic processes.

b. ***Changes to the pattern of flow will change the timing, growth and abundance of fishes within the diversion reach.***

The proposed design proposes that up to 90% of instream flow be diverted to power production, creating substantial reductions in instream flow, especially at low flow times of the years.

This hypothesis is considered to be **very likely** due to the very high proportion of water diverted to power production. Change in the pattern of flow may have its greatest effect at the time of spawning migration.

3.4 Downstream Hypothesis

a. Construction of the weir will change the timing and magnitude of gravel and sediment recruitment to the downstream reach.

Although timing of sediment recruitment may change, this hypothesis is considered to be **unlikely** due to (a) the regular maintenance removal of sediment accumulating in the head pond, and (b) the contribution of high monsoon flow to the maintenance of existing geomorphic processes.

b. ***Variations in the rate at which water is released from the powerhouse (ramping rate) will cause stranding of fish and disruptions of the aquatic habitat in the downstream reach.***

It is expected that the UT-1 Project will operate year-round as run-of-river and there will be no peaking mode operations. Rapid variations in the rate at which water is released from the powerhouse are therefore not expected and this impact is considered **unlikely**.

3.5 Impacts of the Project

Of the six hypotheses that are presented, three are considered very likely or likely to occur during the operations of UT-1:

- **Hypothesis 3.2.b:** The weir will impair the passage of migratory fish, resulting in a barrier effect that could change in composition and abundance of species upstream/downstream of the weir.

- **Hypothesis 3.2.c:** Fish will be entrained in the penstock and / or stranded in the spillway, resulting in the impairment of downstream migration and potential changes in composition and abundance of species upstream/downstream of the weir.

- **Hypothesis 3.3.b:** Changes to the pattern of flow will change the timing, growth and abundance of fishes within the diversion reach.

Hypothesis 3.2.b and 3.2.c relate to aquatic habitat connectivity and could affect fish mobility and ability to disperse. Depending on the species life cycle and migratory patterns, and the location of key habitats (e.g. spawning, feeding grounds), the barrier effect and restriction of movement caused by these impacts could have effects at the population level.

Hypothesis 3.3.b could affect the availability of adequate habitat and impair fish movement within the diversion reach due to the reduction of flows in this river segment.

The analysis of environmental flows presented in this report focuses on the mitigation of Hypothesis 3.3.b. The barrier effect and entrapment risk predicted under hypotheses 3.2.b and 3.2.c would require a different set of mitigation options which are discussed in Section 7.

4 Aquatic Ecology of the Project Area

The following sections summarized the information available on the aquatic habitats of the Project Area; including a synthesis of relevant literature and the results of a one-year aquatic survey conducted by NESS from August 2013 to July 2014. Based on this information and the potential impacts identified in Section 3, an indicator species is proposed (Section 4.3) to be the focus of the analysis of environmental flows.

4.1 Literature Synthesis: Fisheries in the Gandaki River System and the Trishuli Watershed

4.1.1 Fish inventories

A total of eight historical surveys have documented the presence of 51 species of fish within the Gandaki River System (Rajbanshi 2002, DOFD 2008); of which the Trishuli sub-basin is a part. Other sources have reported upwards of 100 species in the Gandaki-Narayani system (Edds 1985, Shrestha 1990, Smith *et al.* 1996), but these surveys include extensive lower elevation portions of the river network. Among the five larger basins of the Gandaki River (Figure 4-1), the Trishuli River basin has the highest species diversity within the Gandaki, with historical surveys recording 47 species (Table 4-1).

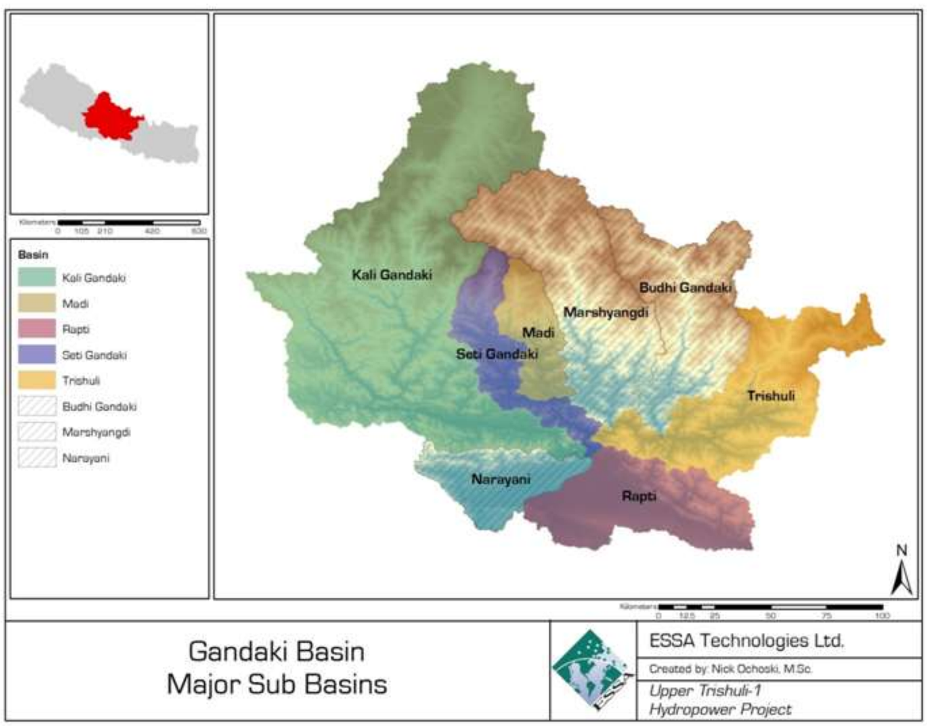


Figure 4-1: Major sub-basins of the Gandaki River system. The five sub-basins shown in color have been surveyed in the historical fish inventories summarized in Table 4-1.

Studies suggest that the fish assemblage of the Gandaki/Narayani is very similar to the groups of species found in other major rivers in central Nepal, such as the Koshi and the Karnali. It is believed that fish assemblages in the tributaries of the Gandaki would follow an altitudinal distribution of fish assemblages along the river profile based on their ecological preferences, as observed in the Bagmati River (Shresta 2002): Snow trout zone (1875 m – 3125 m), dominated by *Schizothorax plagiostomus* and *Schizothorax* spp; Stone carp zone (1250 m – 1875 m) dominated by Stone carp (*Psilorhynchus pseudecheneis*), stone roller (*Garra gotyla*), loach (*Noemacheilus* spp.) and sucker catfish (*Glyptothorax* spp); and Hill 19arbell zone (625 m – 1250 m) dominated by mahseer (*Tor tor*, *T. putitora*) and katle (*Neolissocheilus hexagonolepis*).

In the case of the Trishuli watershed, the number of identified fish species also varies according to the different studies; from the 33 species identified by Gubhaju (2002) to the 46 cold water species that, according to Rajbanshi (2002), are found in the Trishuli basin. As in the Gandaki River, there seems to be a declining trend in the number of fish species from the lower to upper reaches of the Trishuli River. The limnological study of 2007-2008 conducted in the middle-upper part of the Trishuli watershed (Figure 4-2) by the Directorate of Fisheries Development (DOFD) validated this trend. A total of 19 fish species were reported in the five stations studied in this survey (Figure 4-2) with *Schizothorax richardsonii* contributing to 75% of the total catch at the five sampling locations.

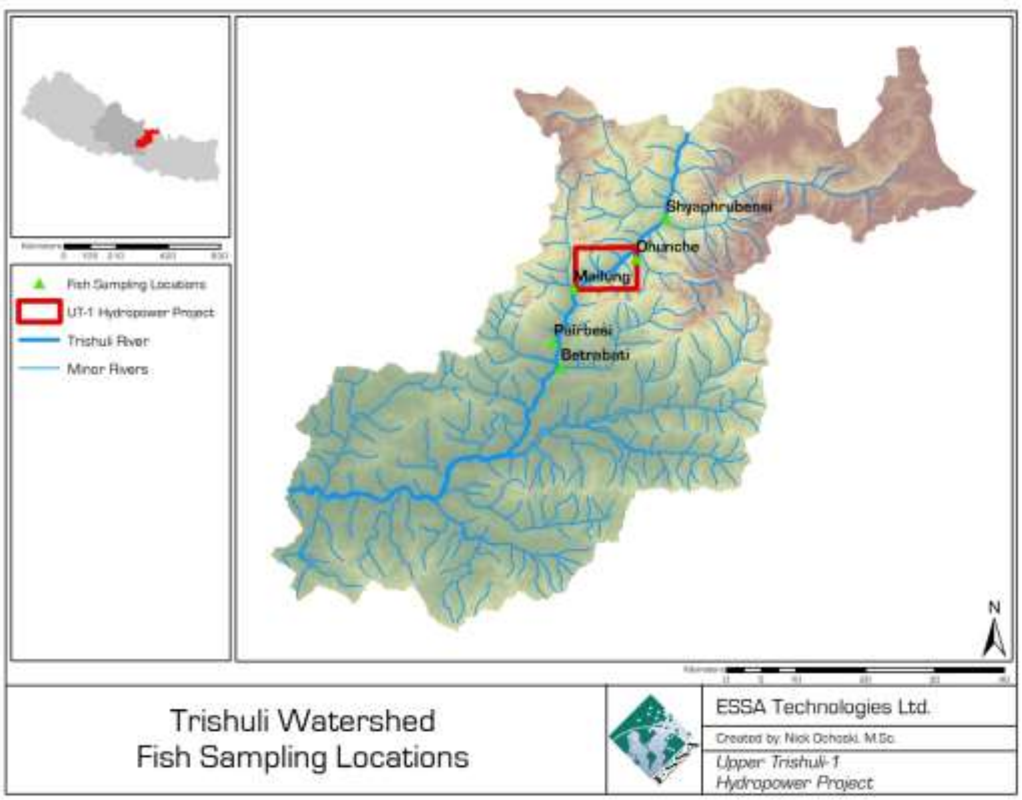


Figure 4-2: Five fish sampling locations of the DOFD (2008) survey are marked with green triangles. The UT-1 Project area is indicated by the red rectangle.

The EIA study (NEA 2010) of the Upper Trishuli-3A, located immediately downstream of the Upper Trishuli-1, reported a total of 13 species based on information by local fishermen and the sampling conducted during the EIA survey. Upstream of the Project, the EIA study for the Rasuwagadhi Hydroelectric Project (NESS 2010), located south of the Tibet boarder, reported a total of 4 fish species (*Schizothorax richardsonii*, *Pseudechneis telchitta*, *Glyptothorax trilineatus*, and *Psilorchynchus pseudecheneis*) based on information provided by locals but only one of these species, *Schizothorax richardsonii*, was actually sampled.

The original EIA study of the Project (Jade Consult 2011) reported only two species of fish; *Schizothorax richardsonii*, and *Schizothoraichthys progastus*, based on observations of the local fishermen catch. Further upstream in the Trishuli River.

All these fish inventories point to the abundance, in the upper part of the Trishuli watershed, of the snow trout *Schizothorax richardsonii*, locally known as *buche asla*, and which is listed as vulnerable (VU) in the IUCN Red List[4]. Among the other fish species reported for the upper part of the Trishuli basin, the migratory copper mahseer (*Neolissochilus hexagonolepis*) has also been assigned a Near-Threatened (NT) status by the IUCN, and has been observed near the tailrace and at sites further downstream (DOFD 2008) of the location of the future powerhouse of the project. Finally, the golden mahseer (*Tor putitora*) has also been observed near the tailrace and at sites further downstream, and is considered Endangered (EN) by the IUCN. It should be noted that the Government of Nepal has not declared any of the riverine fish species in the country as species of conservation significance.

[4] http://www.iucnredlist.org/details/166525/0

Table 4-1: **Fish species recorded within the Gandaki River basin and its five major sub-basins**. Sub-basin locations are shown in Figure 4-1. Spatial scale of each survey diminishes from left to right. Smaller survey regions within the Trishuli River sub-basin are shown with medium and light shading, depending on the spatial scale of the survey (See **Error! eference source not found.** for locations). The right-most column shows survey results for the current EIA. Five species shaded in the left-most column are IUCN-listed for conservation concerns; one species has been recorded in the project area.

Species	Gandaki Basin													
	Major Sub-Basins						Upper Trishuli Sub-Basin							
								DOFD 2008						
	First Record	Seti Gandaki	Kali Gandaki	Madi	Rapti	Trishuli	UT-3A EIA 2010	Shyaphrubensi	Dhunche	Mailung	Pairbesi	Betrabati	UT-1 EIA 2011	Supplemental ESIA 2014
Number of species		7	35	36	41	47	12	5	6	17	18	19	2	2
Acanthocobitis botia	HB													
Acanthophthalmus pangia	HB													
Amblyceps mangois	HB													
Bagarius bagarius	HB													
Balitora brucei	G													
Barilius barila	HB													
Barilius barna	HB													
Barilius bola	HB													
Barilius bendelisis	HB													
Barilius tileo	HB													
Barilius vagra vagra	HB													
Botia almorhae	G													
Botia lohachata	C													
Brachydanio rerio	HB													
Chagunius chagunio	HB													
Channa gachua	–													
Chela laubuca	HB													
Crossocheilus lalius latius	HB													
Danio acquipinnatus	M													
Danio dangila	HB													
Danio devario	HB													
Esomus danricus	HB													
Euchiloglanis hodgarti	–													
Gagata cenia	HB													
Garra annandalei	Ho													
Garra gotyla	G													
Garra lissorhynchus	M													
Garra nasuta	M													
Garra rupicola	–													
Glyptosterrum blythi	–													
Glyptothorax pectinopterus	–													
Glyptothorax telchitta	–													
Labeo angra	HB													
Labeo dero	HB													
Labeo dyocheilus	M													
Labeo gonius	HB													
Lepidocephalus guntea	HB													

Species	Gandaki Basin													
	Major Sub-Basins						Upper Trishuli Sub-Basin							
								DOFD 2008						
	First Record	Seti Gandaki	Kali Gandaki	Madi	Rapti	Trishuli	UT-3A EIA 2010	Shyaphrubensi	Dhunche	Mailung	Pairbesi	Betrabati	UT-1 EIA 2011	Supplemental ESIA 2014
Mastacembalus armatus	–													
Naziritor chelyinoides	M													
Nemacheilus corica	HB													
Nemacheilus multifasciatus	–													
Nemacheilus rupicola	–													
Noemacheilus beavani	NE													
Neolissochilus hexagonolepis	M													
Pseudecheneis sulcatus	–													
Onchorhyncus mykiss	NE													
Psilorhynchoides pseudecheneis	MD													
Psilorhynchus balitora	HB													
Psilorhynchus sucatio	HB													
Puntius conchonius	HB													
Schistura beavani	Gu													
Schistura rupecola rupecola	M													
Schistura savona	NE													
Schizothorax curviforns	H													
Schizothorax esocinus	H													
Schizothorax progastus	M													
Schizothorax richardsonii	G													
Schizothorax niger	H													
Schizothorax sinuatus	H													
Securicula gora	HB													
Securicula bacaila	HB													
Semiplotus semiplotus	M													
Tor tor	HB													
Tor putitora	HB													

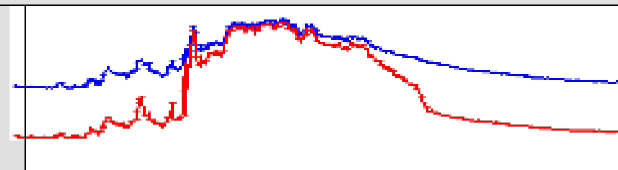
Source: Rajbanshi 2002: C=Chaudhun; G=Gray; Gu=Gunther; H=Heckel; Ho=Hora; HB=Hamilton-Buchanan; M=McClelland; MD=Mennon-Dutta; NE = Sampled by NESS during the 2013-2014 aquatic survey; see Table A1-1 for species synonyms). The five DOFD (2008) sampling locations bracket the UT-1 project site: Shyaphrubensi and Dhunche are upstream; Mailung, Pairbesi and Betrabati are downstream. Other survey sources: UT-EIA 2010 (NEA 2010); UT-1 EIA 2011 (Jade Consult 2011), UT-1 EIA 2013 (NESS 2013)

4.1.2 Fish Ecology

Although surveys provide a fundamental baseline for recording the presence of numerous fish species, a major gap in all the studies reported for the Gandaki and the Trishuli rivers is the general lack of knowledge about the ecology of the fish species present. Key information, such as the life-cycle, habitat preferences, substratum characteristics for spawning, rearing and feeding habits and areas, etc., is unknown for most of the species. Nevertheless, the general Impact Hypotheses (Section 3) are believed to be plausible to all species of fish in the project area

Detailed knowledge of the dispersal or migratory patterns is inconclusive for all but a few species. Table 4-2 summarizes the current state of knowledge of migratory fish species within the Trishuli basin, using Gubhaju's (2002) assignment of dispersal into medium- and long-distance migration. To the best of our knowledge, there is no quantitative information about the range of values that should be assigned to these two classes.

Table 4-2: Migratory and spawning habitat preferences of vulnerable migratory fish species documented within the upper Trishuli basin. IUCN-listed species are shaded in red. The example log-scale hydrograph is taken from Figure 5-2, and shows comparative differences for pre- (upper blue line) and default post-project (lower red line) flow.



Species	IUCN Category	Distance	Spawning Migration & Timing											
			M	A	M	J	J	A	S	O	N	D	J	F
Tor putitora	EN	L			↑	↑	↑	↑	↑	↓	↓			
Neolissochilus hexagonolepis	NT	M			↑	↑	↑	↑	↑	↓	↓			
Schizothorax richardsonii	VU	M	↑	↑						↓	↓			
Labeo angra	LC	M	↑	↑	↑	↑	↑	↓	↓					
Labeo dero				↑	↑	↑	↑	↓	↓					
Schizothorax progastus			↑	↑						↓	↓			

Source: Gubhaju (2002) and DOFD (2008).
IUCN Categories: EN=endangered; NT=near threatened; VU=vulnerable; LC=least concern.
Migration distance: L=long distance migration; M=mid-distance migration.
Timing: ↑=upstream migration; ↓=downstream migration.
Spawning environment: green shading=gravel spawning; blue shading=gravel/pebble spawning.

As indicated in Table 4.2, snow trout species (*Schithotorax*) spawn in two distinct periods: (i) at the start of the monsoon season in March-April; and (ii) at the end of this season in October-November. September/October is considered the best season for spawning (Rai *et al*. 2002). Although the specific factors triggering the fish migration in Nepal are not well known (Gubhaju 2002), it is believed that most of these species react to the increase in flow at the start and during the monsoon season, and move upstream to headwaters to find suitable spawning and feeding grounds. The confluence with the small tributary streams, where conditions of clear water, substratum of pebbles and gravel, low water flows (2.8-4 m/s), pH of 7.5 and dissolved oxygen concentrations of 10-15 mg/L are considered good spawning conditions for snow trout in their natural environment (Rai *et al*. 2002).

Snow trout are a group of 28 cold water riverine and short migratory fish species locally known in Nepal as *Asla*. These species belong to the family *Cyprinidae* and sub-family *Schizothoracinae* and are widely distributed in the Himalayan and sub-Himalayan region. In total, 6 species of the genus *Schizothorax* and 3 species of the genus *Schizothoraichthys* have been recorded in Nepal (Rai *et al*. 2002).

Asla is a phytophagous fish with a specialized mouth to scrape the algae attached on stones. They feed predominantly on attached algae including *Spirogyra*, *Ulothrix*, *Oedogonium*, as well as on the benthic insect larvae of mayflies, caddis flies, ephemeropterans, etc (Rai *et al*. 2002). Fry feed on larvae of chironomids and caddis flies, but also on microscopic algae.

Snow trout are a short-distance migratory fish which enters tributaries for breeding. The presence of a dam can therefore impede these spawning migrations. It migrates downstream during winter and upstream during early June when water becomes turbid (Rai *et al*. 2002). The migration pattern varies from species to species and also depends on the volume of water in rivers and on water temperature. A limonological and biological study by the Directorate of Fisheries (DOFD 2008) found that *S. richardsonii* breeds twice per year: in autumn (September/October) and spring (March/April). This species prefers rapids, pools and riffle types of habitat.

Studies in the mountain streams of the Indian Himalayas (Sehgal 1999) have found variable spawning dates for snow trout (*Schizothoracines*). They remain active in the near-zero Celsius temperatures which prevail in streams during December and January and the rise in temperatures during spring induces spawning. In the Kashmir streams, *S. richardsonii*, *S. longipinnis* and *S. curvifrons* spawn when water temperature reaches 10-17°C during May-June. In the Ravi River system fish have been observed to spawn in May. In the upper Beas, however, the fish spawn only in July-August when the stream water temperature warms up to 16.5-18.5°C.

In the Sutlej River, *S. richardsonii* starts upstream migration with the rise in water temperature during March. During the upstream migration, the fish still finds itself in waters of low temperature of 8.0-9.5°C, owing to the steady influx of snow-melt water. This induces the species to migrate to and spawn in side streams, which receive warm ground water of 17.5-21.5°C. In the same drainage *S. richardsonii* migrates downstream to the lowermost reaches where it spawns from October to December at 19.0 to 22.5°C. These observations indicate that in some schizothoracines multiple spawning is determined by temperatures and flow rates optimal for egg laying (Sehgal 1999). The eggs are laid in shallow pools (50-70 cm depth) and remain adhered to the substratum until the hatching of fry.

With the construction of the project, the creation of a head pond may also provide potential habitat for certain species. For example, *Neolissochilus hexagonolepis*, *Barilius bendelisis*, *Schistura beavani* and *Garra gotyla*; which have all been found downstream from the project area (Table 4-1) are all known to thrive in reservoirs (Swar 1992, Gubhaju 2002). Of the fish species reported upstream of the project area, *Schizothorax richardsonii* is known to do poorly in lake-like conditions.

4.2 Summary of Aquatic Surveys in the Project Area

4.2.1 Aquatic survey methodology

For a one-year period, from August 2013 to July 2014, Nepal Environmental and Scientific Services (NESS) conducted an aquatic survey program in a 15-km long river stretch including the diversion reach (F2, F3 and F4) and the immediate upstream (F1) and downstream reaches (F5). The study area and the monitored river stretches are shown in Figure 4-5.

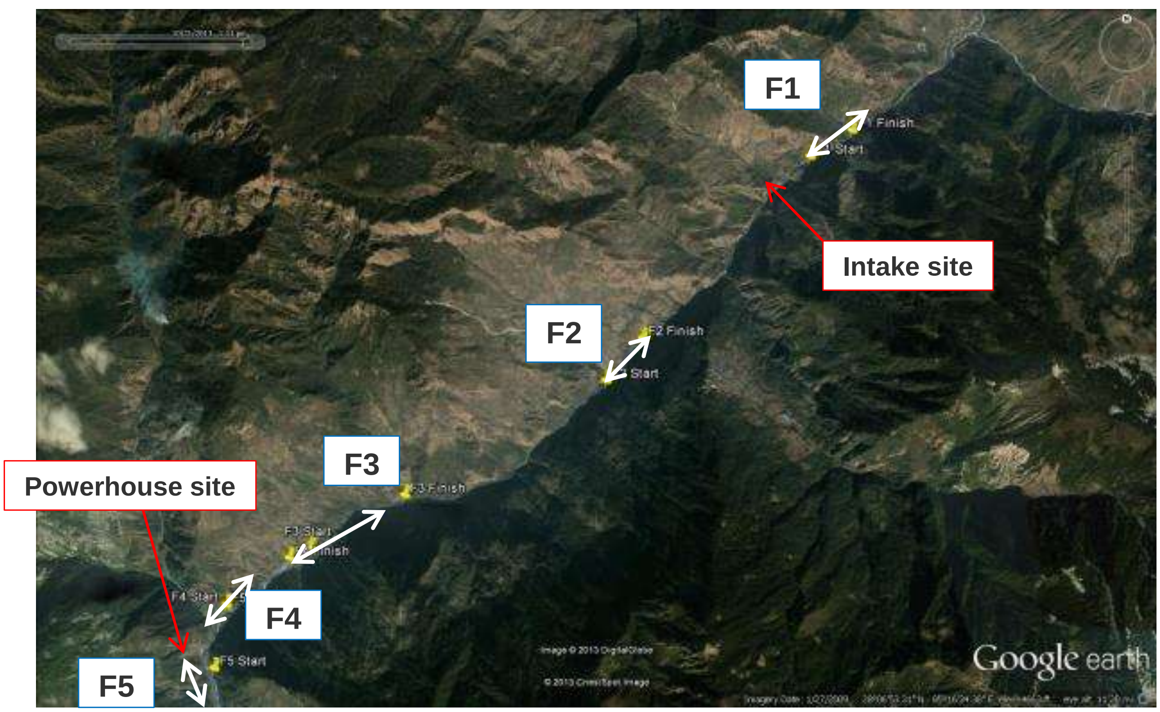


Figure 4-3: Location of monitoring sites for the monthly aquatic habitat and water quality surveys

Fish, habitat parameters (including phytoplankton, periphyton and macro-invertebrates), and water quality were monitored monthly throughout this 12-month period. Fish were surveyed using active (a 4.6 m cast net) and passive (a 5 m gill net) sampling methods. The gill net was set up and left for 12 h at each sampling location. This net could not be extended from bank to bank given the rapid waters of the Trishuli. Instead, sampling was carried along the banks in shallow water representative of the different habitat types. The same monitoring sites were surveyed throughout the study period and habitat characteristics (e.g. wetted river width) were recorded monthly for each of these sites.

4.2.2 Habitat description

The Trishuli is a perennial snow and rain-fed river. Its hydrology and related characteristics, such as water quality, are highly seasonal and influenced by the monsoon rains (roughly from June to August).

At its location in the Project area, the Trishuli is a high gradient river with an estimated drop of nearly 1 m in every 45 m. The river substratum is constituted of boulder (35%), cobble (25-30%), gravel (15-20%), bedrock (15%) and sand (5%). Fine sediments (i.e. silt and clay fractions) are minority components of the river substratum. The adjacent land use on either river bank is dominantly forest with few patches of agricultural land in the downstream reach. Large woody debris is very rare on the river banks. Aquatic vegetation is scarce on the flood plain as well as along the shores.

Aquatic habitat availability shows a seasonal pattern. Wetted widths in all monitoring sites peak in August-September (see Figure 4-4), coinciding with the peak of the monsoon, and are at their lowest during the low flows period (January-March).

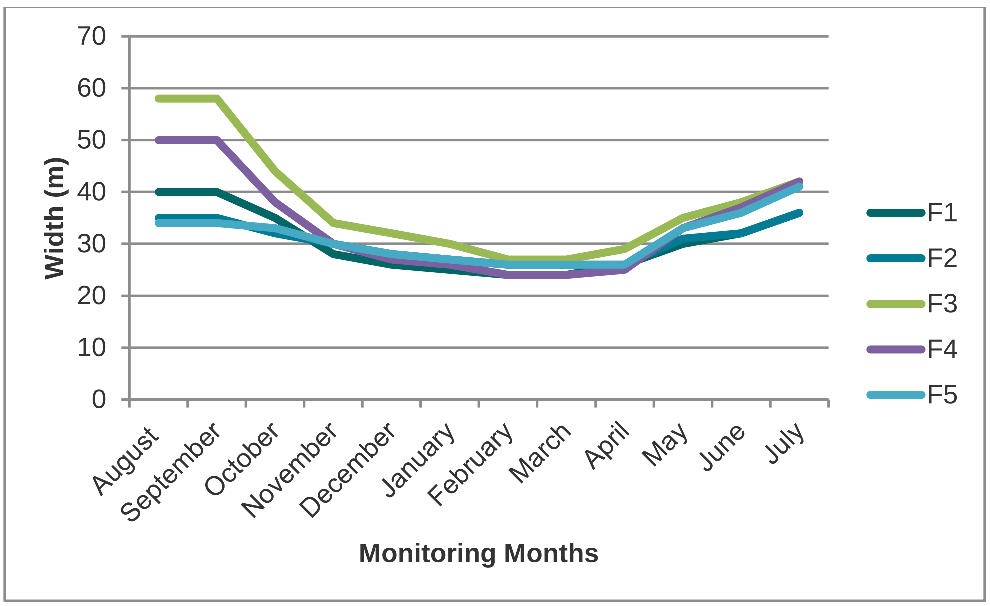


Figure 4-4: Wetted width at the five monitoring locations

The dominant type of aquatic habitat is *riffle* (80-90% of the river stretch) followed by *run* (10-20%). Pool habitat is almost absent. The *rapid-riffle* habitat type increases in relative proportion at the peak of the monsoon (Figure 4-5) due to the increased river flows.

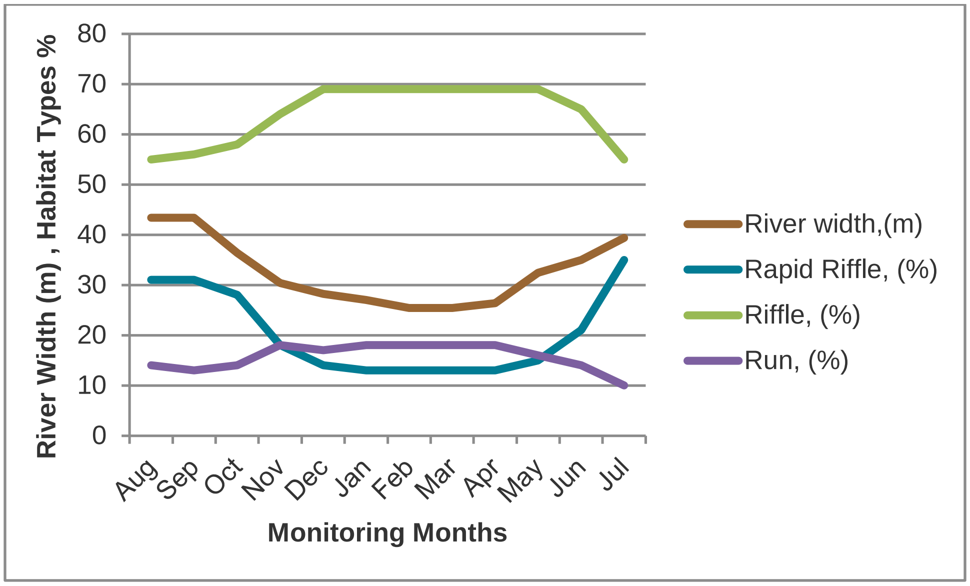


Figure 4-5: Relationship between wetted width and the different habitat types through the year

Hydro-morphologically, the river is very active and shows high erosion and sediment transportation rates. Depositional features such as alluvial cones can be found at the confluence of the Trishuli with the stream tributaries. A major fraction of the river substratum is renewed after each monsoon season.

The availability of fish food sources is also influenced by the hydrological regime. Periphyton and macro-invertebrates densities are lowest during the monsoon peak, and increase gradually as river discharge is reduced. Densities of periphyton and macro-invertebrates show an inverse relationship with the concentration of total suspended solids (Figure 4-6 and 4-7). In terms of primary producers, the year round water quality based on the chlorophyll-a concentration (7.36 mg/l) for the the pre-project scenario.

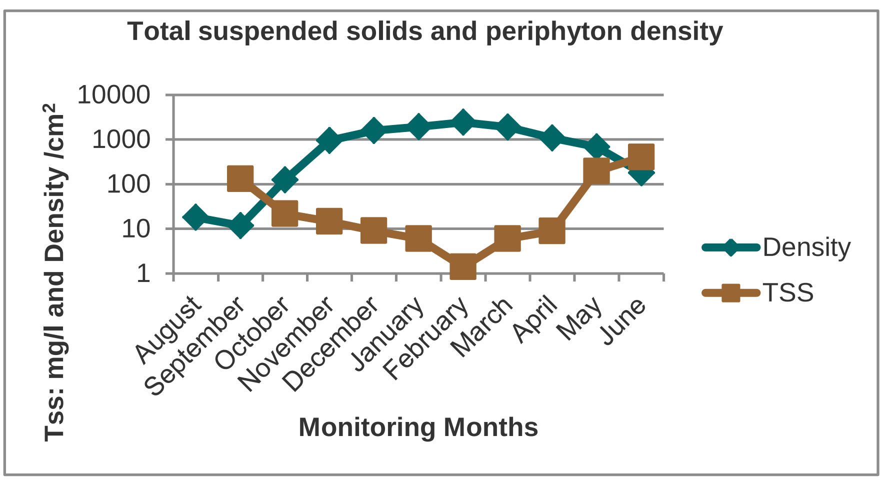


Figure 4-6: Evolution of periphyton density and total suspended solids concentration

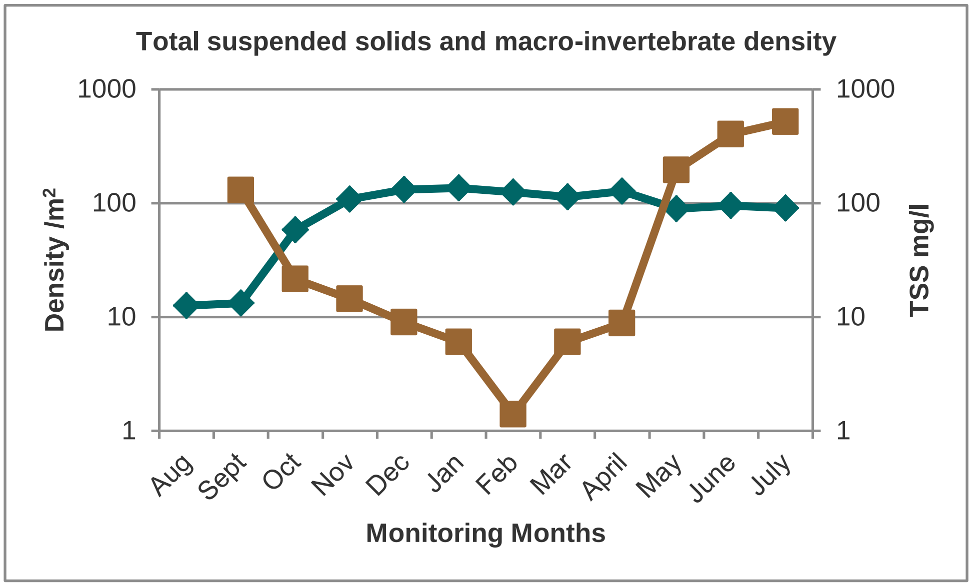


Figure 4-7: Evolution of macro-invertebrates density and total suspended solids concentration

4.2.3 Fish surveys results

A total of 6 fish species were observed during the monitoring period, with the snow trout *Schizothorax richardsonii* as the dominant fish species which was consistently monitored in all monitoring sites through the year (Figure 4-8). It accounted for above 99% of the total fish catch by cast net and 100% of the fish catch by gill net. *Schizothorax richardsoni* was observed throughout the monitoring period, while other species were observed sporadically in the monsoon months.

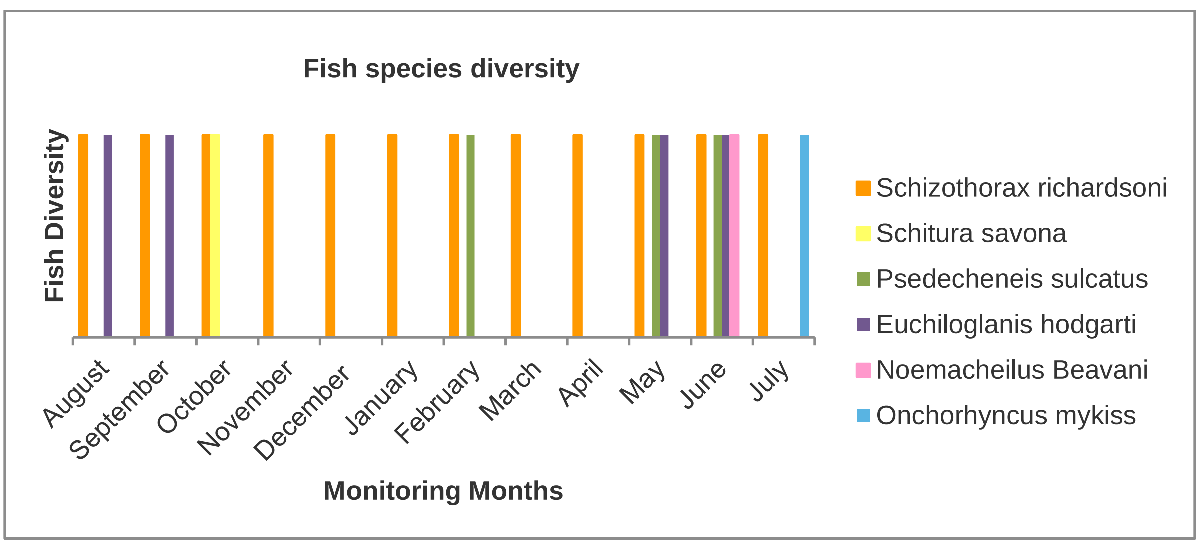


Figure 4-8: Species diversity (presence) throughout the fish survey monitoring period

Of the observed species, *Schizothorax richardsoni* (Buche Asala), *Euchiloglanis hodgarti* (Till Kabre), *Schitura savona* (Gadela), *Psedecheneis sulcatus* (Kabre) and *Noemacheilus Beavani* (Gadela) are all native fish species, while *Onchorhyncus mykiss* (Rainbow trout) is an exotic species probably introduced in the river system from the rainbow trout farms present in the catchment, around the Dhunche in Rasuwa District.

The abundance of *S. richardsonii* shows a seasonal distribution. The peak in the number of specimens captured occurred in the month of September (344 in total in the five sampling locations), coinciding with the end of the monsoon season and likely the start of the downstream migration, and the lowest number was recorded in January (24 in total in the five sampling locations), during the dry period. Higher numbers were captured in the sampling locations in the lower diversion reach (F3 and F4) and immediately downstream of the powerhouse (F5). Figure 4-9 shows the temporal trends of *S. richarsonii* total catch (including both cast and gill net catches) through the monitoring period.

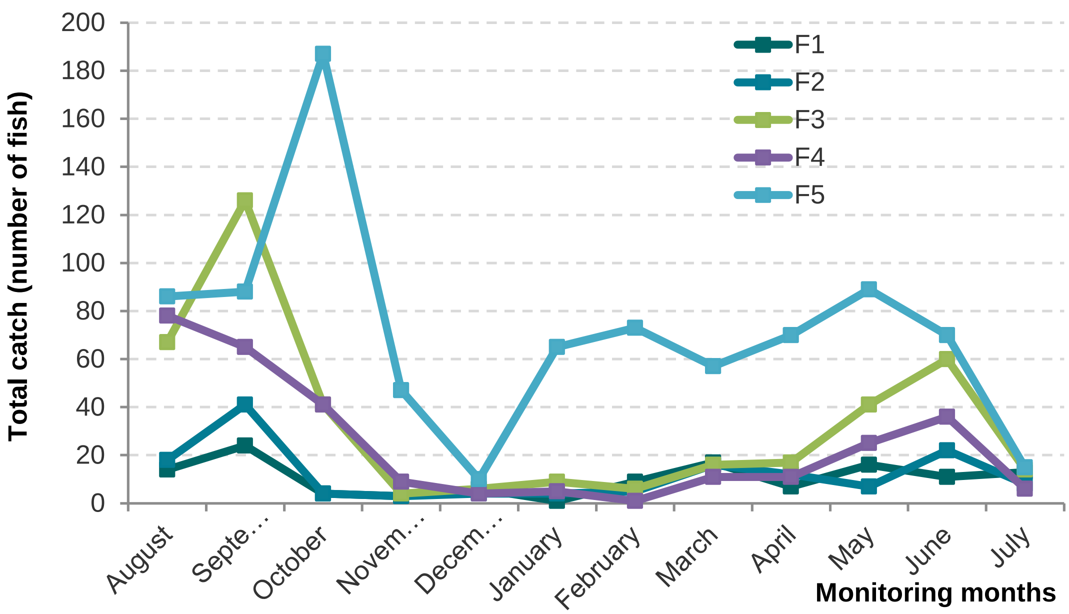


Figure 4-9: Evolution of *S. richarsonii* catch during the monitoring period (August 2013-September 2014) in the five river monitoring stretches

In terms of differences in monitoring results per sampling method, it should be noted that catch per unit effort (Figure 4-10) was lower for the cast net sampling as were the average length and weight of the fish captured through this method. Gill net sampling resulted in greater catches of larger individuals.

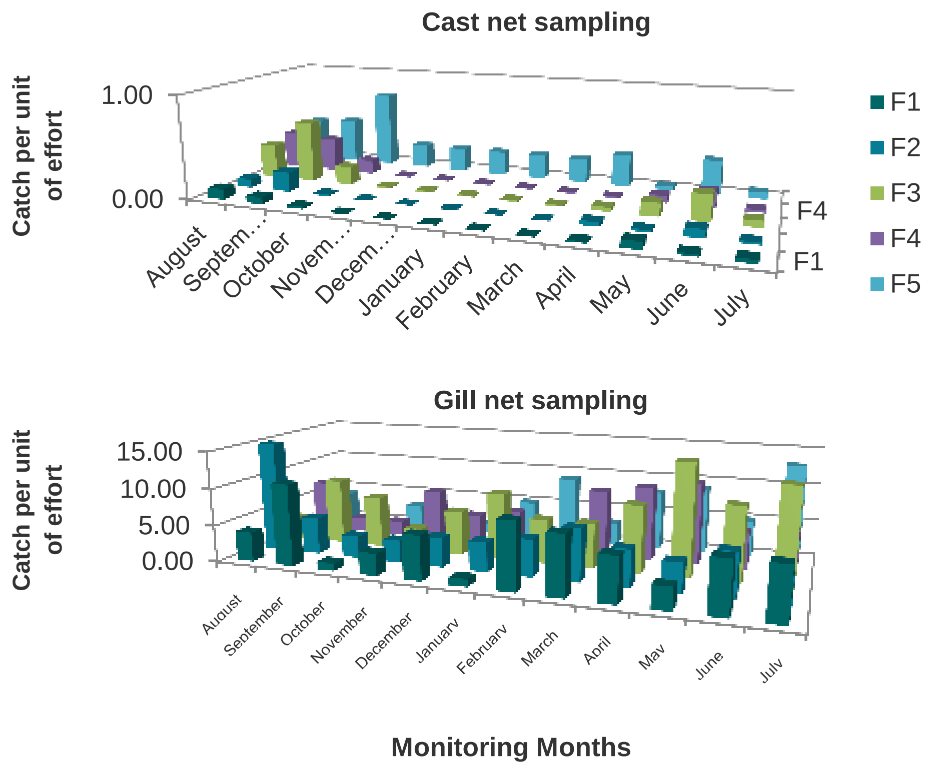


Figure 4-10: Results of catch per unit method for the two sampling methods (cast and gill net) utilized for the fish survey

Field observation of female gonads of the captured specimens of *Schizothorax richardsoni* over the monitoring period showed presence of ovaries with mature eggs starting from July to February (Figure 4-11). No eggs were found during the months of March and April and immature ova were observed in the months of May and June. These observations suggest that spawning in the project area may occur from March to May, before the monsoon season. However, a single monitoring year does not provide enough data to accurately define the spawning periods. Spring spawning is in line with some of the literature[5], which points to April-May as the main spawning period (Vishwanath 2010).

[5] http://www.iucnredlist.org/details/166525/0

Figure 4-11: Observed female specimens of *Schizothorax richardsoni* during the monitoring period

4.3 Indicator Species for Environmental Flows

Based on the knowledge available through a synthesis of literature and inventories past and recent, the snow trout *Schizothorax richardsoni* is identified as the key indicator species to link with the Impact Hypotheses, due to the frequency of its observation in sampling programs around the project site, its IUCN vulnerable status, and its mid-range migratory behavior. *S. richardsonii* is also representative of the ecology of other cold-water species, such as the closely related *S. progastus*, which although it has not been sampled in the area in the recent EIA studies, has been observed both upstream and downstream of the

UT-1 site (DOFD 2008) and has migratory and spawning habits which are similar to *S. richardsonii*.

There are no obvious indications of natural passage barriers, and *S. richardsonii* is a therefore a plausible candidate for experiencing the impacts of both passage barriers (Hypothesis 3.2.b and 3.2.c), that could affect the ability of this species for accessing spawning/feeding habitats and therefore complete its life cycle, and changes to flow quantity and timing (Hypothesis 3.3.b), that could affect the availability and quality of habitat in the diversion reach as well as the connectivity and ability of *S. richardsonii* to move up and downstream within this segment.

As previously discussed, there is limited detailed information about the ecology and life-history of this species and further surveys are required to characterize the population dynamics (temporal and spatial) of *S. richarsonii* in the project's area of influence.

The species is known to migrate upstream in March and April and also spawn around this period, at a time of the year when the project will create a very marked alteration of the natural hydrograph (Figure 5-2). According to the literature, another spawning period of snow trout would occur during the fall downstream migration (October-November). Spawning of snow trout is expected in areas with lower flow velocity and a gravel and pebble substratum (Gubhaju 2002). This type of environment in the Trishuli can be found at the confluence of the stream tributaries with the Trishuli. Figure 4-12 shows the location of such 21 confluences between the weir and tailrace, with an additional 60 confluences spread over 15 km in each direction upstream and downstream of the project. The linear density of potential spawning locations is similar at all locations, suggesting the widespread potential for migration and dispersal in the absence of passage barriers.

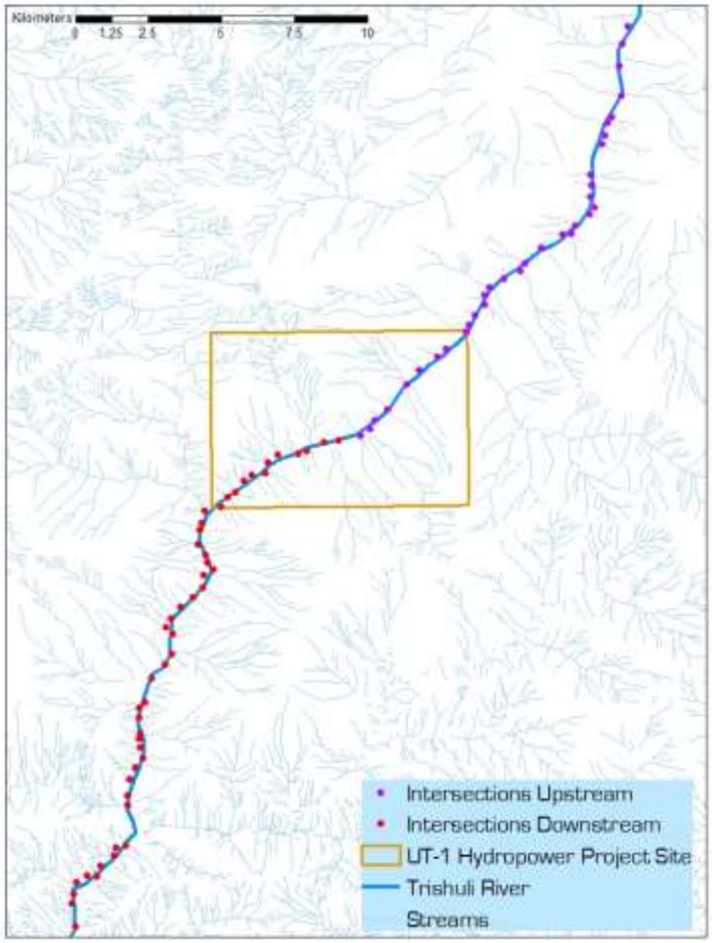


Figure 4-12: Intersections of tributary streams with the Trishuli River are shown for the UT-1 Project area and 15 km upstream and downstream.

Throughout the same river reach there are no obviously impassable vertical gradients or waterfalls that would clearly limit dispersal or migration. Figure 4-13 shows a river elevation profile created through analysis of existing GIS coverage, and shows how the river elevation rises faster at middle elevations (700 – 1400 m) before declining above 1,400 m, but does not change abruptly at any location (allowing for the accuracy of remotely sensed elevation).

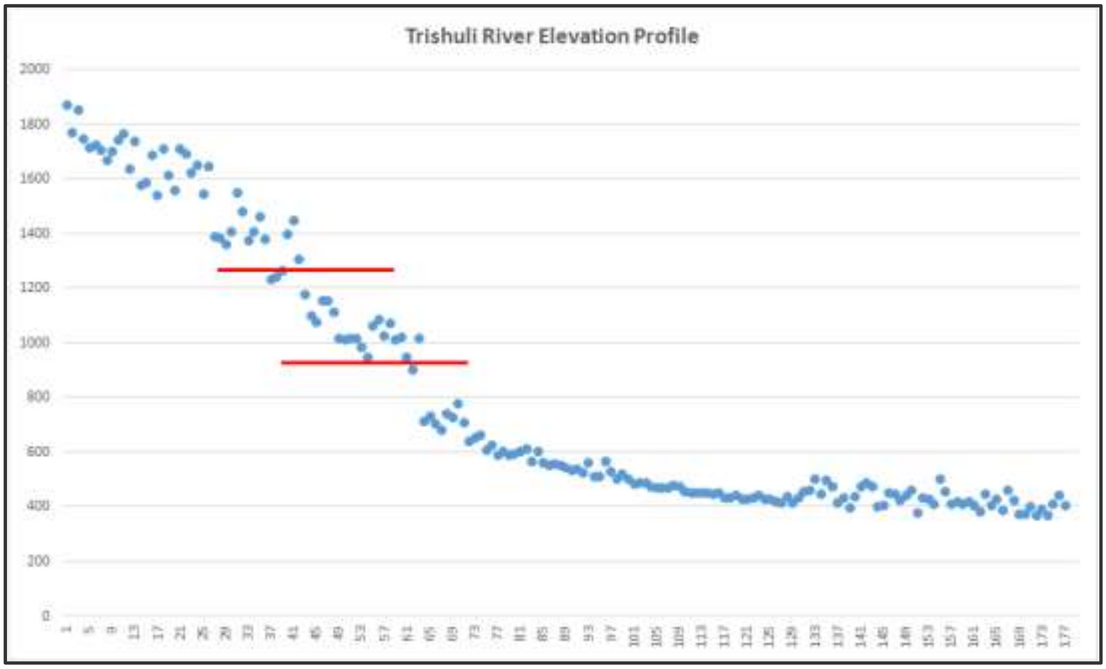


Figure 4-13: Elevation change of the Trishuli River within the UT-1 Project area. Red lines mark the weir elevation (~1,250 m) and tailrace elevation (~910 m). Imprecision in elevation estimates (jitter) is due to the limitations of remote sensing resolution.

Further sampling is required to adequately define the spawning periods and location of spawning habitats for the local snow trout population, as well as the precise timing of the upstream and downstream migrations.

Despite its wide geographic distribution in the Himalayan region, recent observations over the last 5 to 10 years indicate drastic declines in many areas of its range due to introduction of exotics, damming and overfishing (Vishwanath 2010). The current trend of hydropower development in the Trishuli watershed (see Figure 2-5) and other sub-basins in the Gandaki river system suggests that there is a potential for cumulative impacts to these species that should not be overlooked. Of equal concern is the importance of these food fishes to the livelihoods and food needs of local communities. Project activities which cannot be mitigated and which prevent these species from completing their life cycle will likely have negative consequences for the local communities.

Another potential risk affecting the local population of snow trout is the introduction of exotic salmonids, such as rainbow trout (*Onchorhyncus mykiss*) from fish farms in the region. Rainbow trout adults feed on juvenile *Schizothorax richardsonii*, as observed during the survey.

5 Environmental Flow Assessment

5.1 Introduction

In addition to the potential for hydroelectric generation, the Trishuli River provides other intrinsic benefits: biological, ecological and hydrological values ("ecosystem services") which all aquatic systems provide to local human communities and the wider regional ecosystems in which they are embedded. To help decide among water management options, resource managers require methods to evaluate the benefit and costs of different allocation schemes. These intrinsic benefits are often encapsulated through the concept of ecological or environmental flows (Smakhtin *et al.* 2006): *the flow pattern required to maintain normal ecosystem function*.

Numerous methodologies have been developed to quantify the effects of flow alteration on ecosystems, and with over 50 years of international concern about the effects of flow alteration on ecosystems, the development of scientifically based tools to quantify the ecological effects of flow regulation and river channel alterations has become a prominent research activity (*e.g.*, Bunn and Arthington 2002; Arthington *et al.* 2006; Poff *et al.* 1997; Poff and Zimmerman 2010). At one extreme are detailed holistic process-based models that integrate multiple physical variables with functional relationships linking physical processes to geomorphological processes and ecological components such as the life history requirements critical fish or plant species. At the other extreme are the much simpler "desktop" methods described below, which rely on the near-maintenance of the hydrograph as a proxy for more detailed ecological and species needs.

In the context of Nepal, there are many gaps to the application of holistic process-based models to evaluate habitat and normal ecosystem functioning. In the absence of sufficient knowledge to apply more complex models, ***maintaining hydrology is used as a proxy for maintaining habitat and ecosystem function***, and most have advocated a simplified approach in which a minimum level of instream flow is maintained, with the residual being available for other uses. For example Tennant (1976) recommends that 10% of mean annual discharge should be maintained for ecological purposes. Such simple methods are often referred to as desktop methods, since they do not require enormous investments of time for basic research, development and field testing. The key concept behind desktop analysis methods is to compare the pre-development flow regime (*e.g.*, a daily hydrograph) with the post-development regime, so that key features of the two regimes are preserved. This can involve simple prescriptive rules such "preserve instream flow as 10% of mean annual discharge" (Tennant 1976).

A more common ecological paradigm (see Richter *et al.* 2012) is one of setting **"presumptive flow standards"** in which much higher instream flows are proposed, to preserve ecological function in the face of incomplete knowledge. Richter *et al.* (2012) suggest that

> **"… until Ecological Limits of Hydrologic Alteration (ELOHA) or some variation can be applied everywhere, a presumptive, risk-based environmental flow standard is needed to provide interim protection for all rivers."**

Recently, Locke and Paul (2011) reviewed the environmental flow literature and recommended that instream flow should be maintained at 80% of discharge (Locke and Paul 2011), guaranteeing a minimum flow and a maximum withdrawal proportion. This is consistent with Richter *et al.*'s recommendation that **"a moderate level of protection is provided when flow are altered by 11-20%"**, making allowance for greater depletion during seasons of flow levels during which aquatic species are less sensitive. More complex methods such as the Indicators of Hydrologic Alteration (IHA; Richter *et al.* 1996) measure changes to the flow regime in numerous ways ranging from minimum and maximum flows over daily, weekly and longer timescales; ramping rates and extreme events.

In the following parts of this section the unimpaired flow of the Trishuli River is characterized, which forms a baseline for comparison with the design flow and for two alternative instream flow scenarios. All scenarios are evaluated through an examination of their hydrographs (a proxy for habitat) and also through the application of the IHA software, as described in Section 5.4.

5.2 Design Flow Scenario

The design rules by which the system of 3 turbines will be operated will determine the amount of water that is diverted to the turbines and by subtraction, the amount of residual flow to the Trishuli River channel between the weir and the tailrace. The default operating assumptions are found in the Power Generation Chapter of the Daelim Kyeryong Basic Design Report (hereafter DK (2011b)), which describes the methodology for computing average predicted power generation through the year and indirectly provides a basis for quantifying the operating assumptions.

The engineering design (DK 2011b) took into consideration the historical average discharge for each month based on daily Betrawati gauge data (1967-2010) for the purpose of hydrological analaysis. The gauge data has been scaled downward by a factor of 0.8971 to account for the slightly smaller watershed area above the intake, situated 12 km upstream from the gauging station. In order to clarify the DK diversion rules, monthly average discharge data taken from DK (2011b) Figure 5-1 shows the relation between diverted and residual flow as a function of incoming flow at the diversion point, applying a maximum diversion rate of 76 m^3/s. An example of the outcome of applying this DK diversion rule is shown in Figure 5-2.

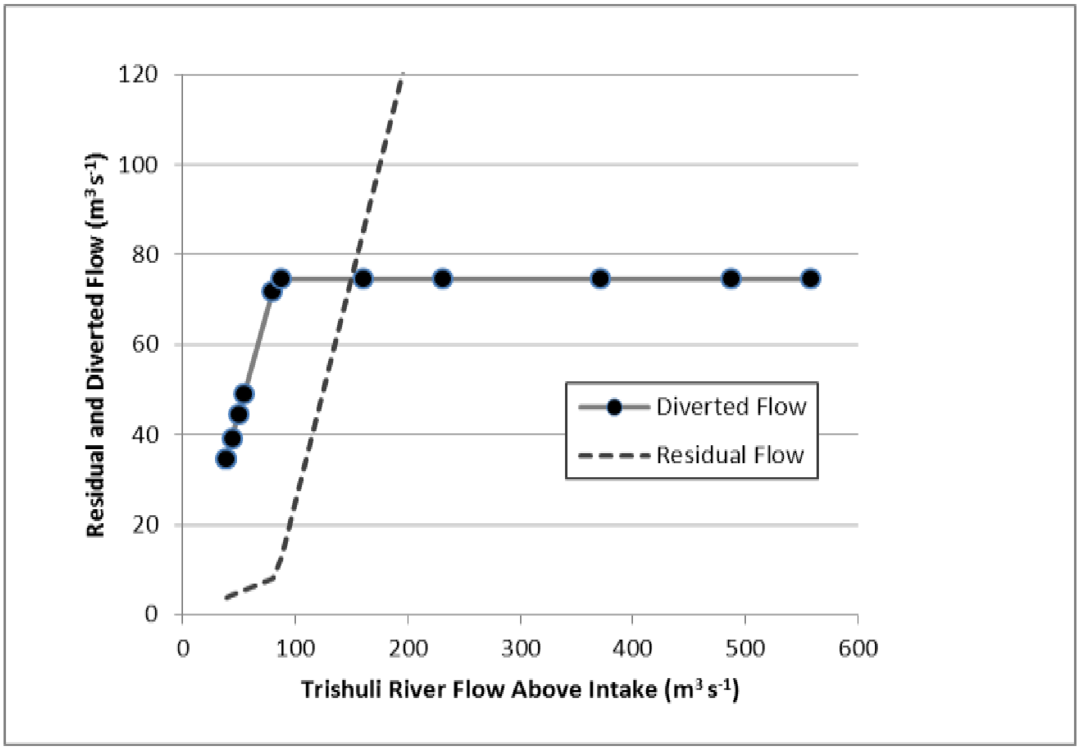


Figure 5-1: Diverted and residual flow in the Trishuli River channel between the intake weir and the downstream tailrace. Design assumptions indicate that excess water will spill over the weir when discharge exceeds the design maximum of 76 m^3s^{-1}, and that below the design maximum design limit, water diversions will be reduced toward zero.

There are markedly different slopes for the high- and low- flow segments of the lines in Figure 5-1. These different slopes indicate that before accounting for any ecological flow or other consumption needs, for power generation purposes when the Trishuli River flow falls below the power system's design maximum (76 $m^3\ s^{-1}$), 90% of flow is diverted for power generation, leaving 10% for ecological and other needs. (In this respect the design is reminiscent of Tennant (1976), who recommends that residual flow be set at 10% of mean annual discharge.) When diversion flow exceeds the maximum, all excess water spills over the upstream intake weir. These diversion assumptions are the default operating assumptions, and appear to hold at least until flow declines to 38.6 $m^3\ s^{-1}$; corresponding to the minimum monthly average flow for February and March.

The choice of this design maximum was likely influenced by the daily hydrograph, which has a median value of 77 $m^3\ s^{-1}$ over the 44-year period of the historical record. Basing the design on the 50th percentile of the hydrograph means that on average the design maximum will be unmet half the days every year. When this happens and flow declines below the design limit, the relationship between diverted and residual flow will change as shown by the rules in Table 5-1.

Table 5-1: Flow operating rules inferred from the DK (2011b) design report

Flow Condition ($m^3 s^{-1}$)	**Diverted to Power ($m^3 s^{-1}$)**	**Residual Flow ($m^3 s^{-1}$)**
Q > 84.4	D = 76	R = Q – D
14.1 ≤ Q ≤ 84.4	D = 90% x Q	R = Q – D
Q < 14.1	D = 0	R = Q – D

The engineering design (DK 2011b) determine the number of turbines operating for each average monthly flow. This table indicates that as flow declines below the design maximum, turbines will be sequentially deactivated to maintain efficient power generation for the remaining operating turbines. Using an individual turbine capacity of 25.3 $m^3 s^{-1}$, the design data indicate that when flow falls below 50.7 $m^3 s^{-1}$ one turbine will be withdrawn from service. Presumably a second turbine would be taken out of service in the rare event that flow declined below 25.3 $m^3 s^{-1}$ and the remaining turbine would hypothetically operate until diverted flow was reduced to 12.7 $m^3 s^{-1}$; the minimum operating flow for a single turbine. Therefore, only one turbine operating at a 12.7 m^3/s capacity would correspond to an incoming flow of 14.1 m^3/s at the intake site (considering that 10% of that flow would be release into the diversion reach as environmental flow), as shown in Table 5-1. It should be noted that these extreme low flow rules are hypothetical. The lowest one-time daily flow ever observed at the UT-1 weir is 25.5 m^3/s.

The constraints inferred from the DK (2011b) power production estimates can be combined to concisely express the default operating rule shown in Table 5-1. The DK (2011b) operating rule can be applied to create the hydrographs in Figure 5-2, which clearly show the impact of the operating rule at lower flow times of the year, during both low-flow and high-flow years.

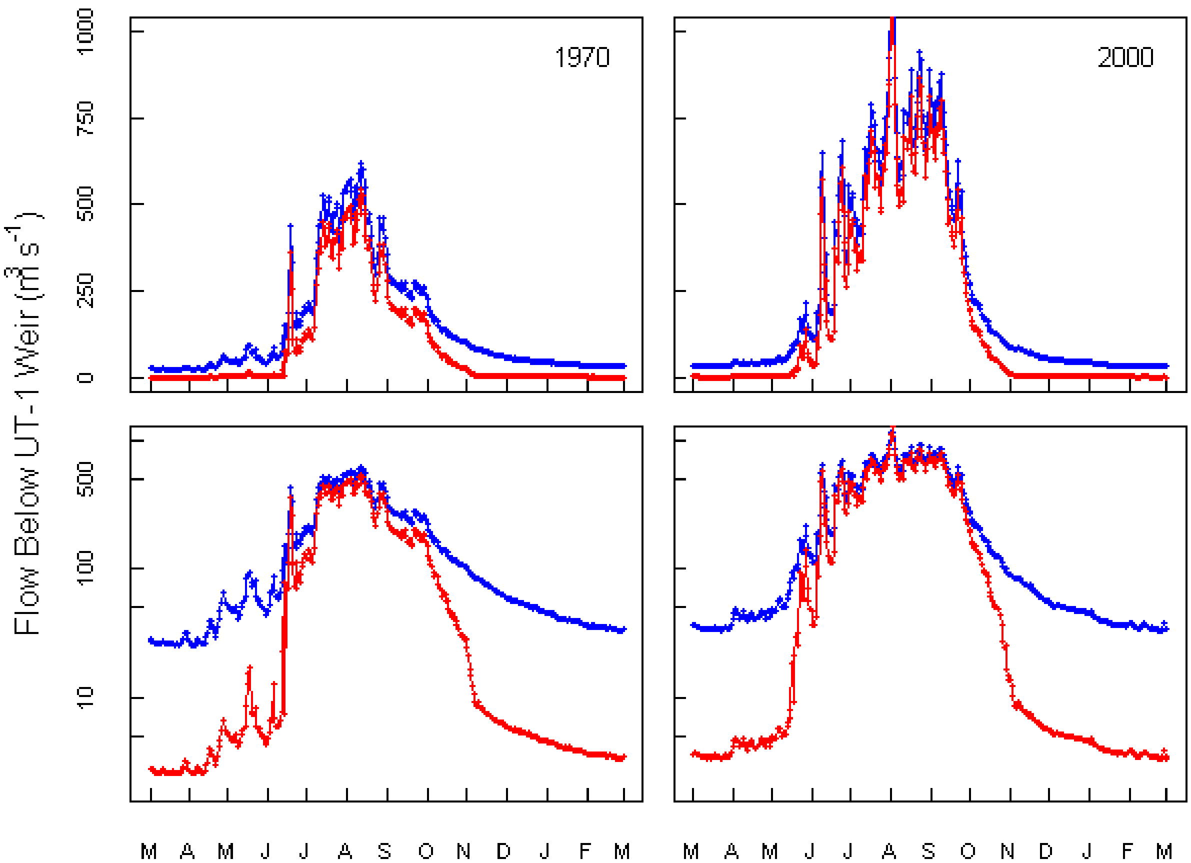


Figure 5-2: Daily flows for representative low-flow (1970) and high-flow (2000) years The graphs show the range in discharge during the June-October monsoon under the unimpaired baseline case (upper blue line) and the DK (2011b) operating rule (lower red line). Upper graphs use a linear vertical scale which captures the extreme flows of the monsoon. Lower graphs show the same data with a logarithmic scale to show greater detail outside the monsoon period.

The impact to residual flow of incorporating this management regime is also shown through the exceedance plot in Figure 5-3. Exceedance plots are commonly used by hydrological engineers for operational planning, and remove the time dimension of the hydrograph by sorting all observed flows into a cumulative distribution in which the left most (0%) point on the graph shows the highest flow ever observed, and the right-most (100%) point shows the lowest flow ever observed. The median flow then corresponds to the 50% point on the horizontal exceedance axis. Comparing the baseline flow and the DK (2001b) operating rule flow in Figure 5-3, the substantial design diversion of up to 90% has a very large impact on the exceedance curve, which becomes increasingly evident as pre-diversion flow declines toward 84 $m^3 s^{-1}$, then flattens as unimpaired flow falls below that. As noted above, flows below the lower critical point of 14.1 $m^3 s^{-1}$ have never been observed at this location of the Trishuli River, and so the 3rd rule in Table 5-1, for extremely low flows, is never invoked with the current historical data.

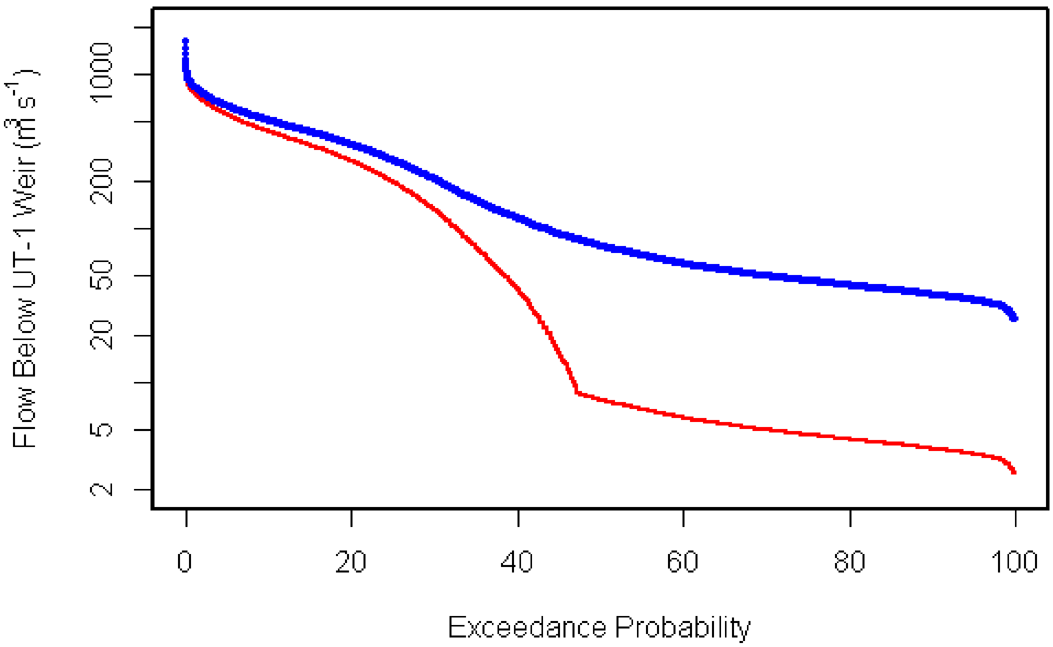


Figure 5-3: Exceedance plot showing the distribution of baseline 1967-2010 historical discharge below the UT-1 weir (upper blue points), compared to the residual flow (lower red points) using the DK (2011b) operating rule. The y-axis has been transformed to a logarithmic scale because of the very high range of flow.

In anticipation of a discussion of unmanaged and managed flow regimes and ecological requirements (Section 5.3), Figure 5-4 shows exceedance plots for the DK (2011b) design, based on the monthly distribution of historic flows. The figure shows that the July-September peak monsoon flows are very similar for both the unimpaired and managed river, with the shoulder months of June and October being quite similar over much of the flow-distribution. These similarities suggest that geomorphic processes operating under high flow regimes (median flow ~400 $m^3 s^{-1}$) will continue to operate normally (ignoring the role of the weir in altering sediment transport) after the UT-1 facility is operational. During lower flow months the distribution of managed flow is typically 10% of the unmanaged case, which agrees with the DK (2011b) operating rule.

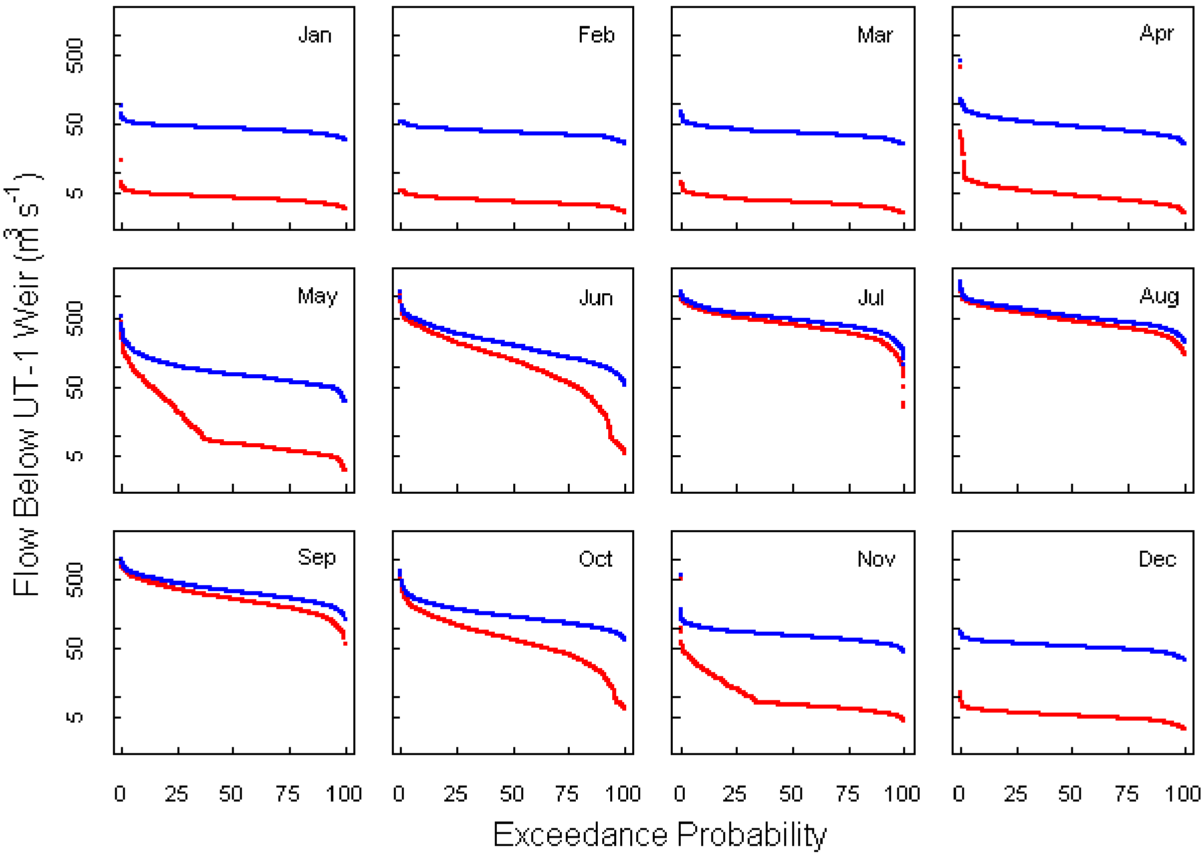


Figure 5-4: Monthly exceedance plots showing the distribution of baseline 1967-2010 historical discharge below the UT-1 weir (upper blue points), compared to the residual flow (lower red points) using the DK management rule. The y-axis has been transformed to a logarithmic scale because of the very high range of flow.

5.3 Alternative Environmental Flow Scenarios

The proposed operational flow rules described in Section 4.3 may conflict with an environmental requirement for a near normal flow regime around the migratory and spawning period of *S. richardsonii*, which was identified as a key indicator species in Section 4.3. The release of environmental flows into the diversion reach has the potential to mitigate the impacts associated to Hypothesis 3.3.b; which, as mentioned in Section 3.3, states that changes to the pattern of flow in the diversion reach could result in changes to habitat availability and quality and to the mobility within the diversion reach (e.g. access to spawning grounds), thus impacting the growth and abundance of fish within the diversion reach.

In the absence of more accurate eco-hydrological information, this report presents a sensitivity analysis of impacts to power generation of increased environmental flow options during the critical period of March-April, when upstream migration and spawning of *S. richardsonii* takes place. Increased flows during this period would replicate the cue for upstream migration and facilitate the movement of *S. richardsonii* towards its spawning habitat locations.

From the limited available life-history information, *S. richardsonii* is known to migrate upstream in March and April and downstream during October and November (Table 4-2). Because the upstream migration coincides with low mean monthly flows (3.9 and 5 m^3/s for March and April, respectively, compared to 160.4 and 79.9 m^3/s in October and November. See Table 5-3), the alteration of the hydrograph (Figure 5-2) will be more marked during this period and it has been selected for the analysis of alternative flow scenarios and the sensitivity test (Section 5.5). Although tributary and groundwater inputs may offset reduced river flow in the diversion zone, the magnitude of these sources is not yet known.

Incorporating spawning migration of *S. richardsonii* as a significant indicator with the presumptive flow standards described in Section 5.1, this report has developed two alternative flow scenarios which seek to provide significant hydroelectric power as well as providing snow trout with a nearly normal environment during their upstream migratory period. These scenarios therefore provide possible mitigation for the likely impact of the Impact Hypothesis **3.3.b,** as described in Section 3.3.

It should be emphasized that this analysis is a first step on the determination of the most appropriate environmental flow regime for the UT-1 Project. Key knowledge gaps (e.g. migration range, spawning locations, etc.) are outstanding and further monitoring of local aquatic habitats, pre- and post-construction, and studies as well as coordination and engagement with engineers, aquatic specialists, relevant stakeholders and local water users, are all necessary steps to fill in these gaps and to develop the required Environmental Flows Management Plan, as described in Section 7. It is expected that the final appropriate level of environmental flow will be determined in an adaptive manner (Annex 4) through testing different flow levels and incorporating the monitoring results that will help fill in the knowledge gaps.

We have evaluated two alternative flow management scenarios, which imply an increased release of environmental flow during the March-April period, in addition to the default design flow assumption (i.e. 10% of the unimpaired flow):

- **80% of the mean monthly unimpaired flow**. This scenario is consistent with conservative the presumptive flow standard recommended by Richter *et al.* (2012) for situations where there is incomplete ecological knowledge. This level of flow should provide interim protection for all rivers.

- **50% of the mean monthly unimpaired flow.** This scenario represents a lower level of increased flow during the critical period. It was included to test the sensitivity of power generation to higher environmental flow releases.

These flow alternatives are not prescriptive, but are used to frame the sensitivity analysis and guide the quantification of the impact upon generating capacity of providing improved environmental flow during the migration period.

Outside the migration months the operating rule is identical to the default design flow rule. Because both alternative scenarios provide greater unimpaired flow than the default design flow scenario they will inevitably yield less power compared to the baseline production estimate. Estimates of power production under the design, 50% and 80% flow scenarios are presented in Annex 3.

Table 5-2 provides an estimation of the incoming flows into the diversion reach based on the mean monthly flows at the intake site (start of the diversion reach) based on the mean monthly flows at this points and the different environmental flow scenarios (diversion rules), including the 80 and 50% scenarios used for the sensitivity analysis:

Table 5-2: Incoming flows into the diversion reach based on the mean monthly flows at the intake site and the studied environmental flow scenarios or diversion rules (flow values shaded in green indicate the critical period of upstream migration during March-April)

Flow management scenarios		Mean monthly flow (m^3/s) at the intake site											
		Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
Unregulated[1]		38.6	49.5	87.5	230.4	487.0	557.8	370.8	160.4	79.9	54.6	43.7	38.6
Regulated	DK design[2]	**3.9**	**5.0**	11.5	154.4	411.0	481.8	294.8	84.4	8.0	5.5	4.4	3.9
	80% March-April	**30.9**	**39.6**	11.5	154.4	411.0	481.8	294.8	84.4	8.0	5.5	4.4	3.9
	50% March-April	**19.3**	**24.8**	11.5	154.4	411.0	481.8	294.8	84.4	8.0	5.5	4.4	3.9
% of mean monthly flow[3]	DK design[2]	**10%**	**10%**	13%	67%	84%	86%	80%	53%	10%	10%	10%	10%
	80% March-April	**80%**	**80%**	13%	67%	84%	86%	80%	53%	10%	10%	10%	10%
	50% March-April	**50%**	**50%**	13%	67%	84%	86%	80%	53%	10%	10%	10%	10%

(1) Unimpaired mean monthly flow at the intake site based on the 44-year Betrawati hydrological series
(2) Currently proposed environmental flow rule: release of a minimum of 10% of the mean monthly flow
(3) Percentage of mean monthly flow at the intake site that would flow into the diversion reach

Plots of flow downstream from the UT-1 weir under one environmental flow scenario – 50% minimum instream flow for March and April – are shown for representative low- and high-flow years in Figure 5-5, clearly demonstrating how the scenario increases flow in March and April so that it is nearly equal to the unimpaired flow. Monthly exceedance plots for the 50% scenario are found in Figure 5-6, and show that relative to the design scenario, changes to flow are confined to March and April. Of those two months, the distribution of flow in March is very close to the line for unimpaired flow, leaving little excess to contribute to power generation. In April the distribution includes a higher proportion of high flow, and therefore a power generation profile that is closer to the design flow profile (see Annex 3).

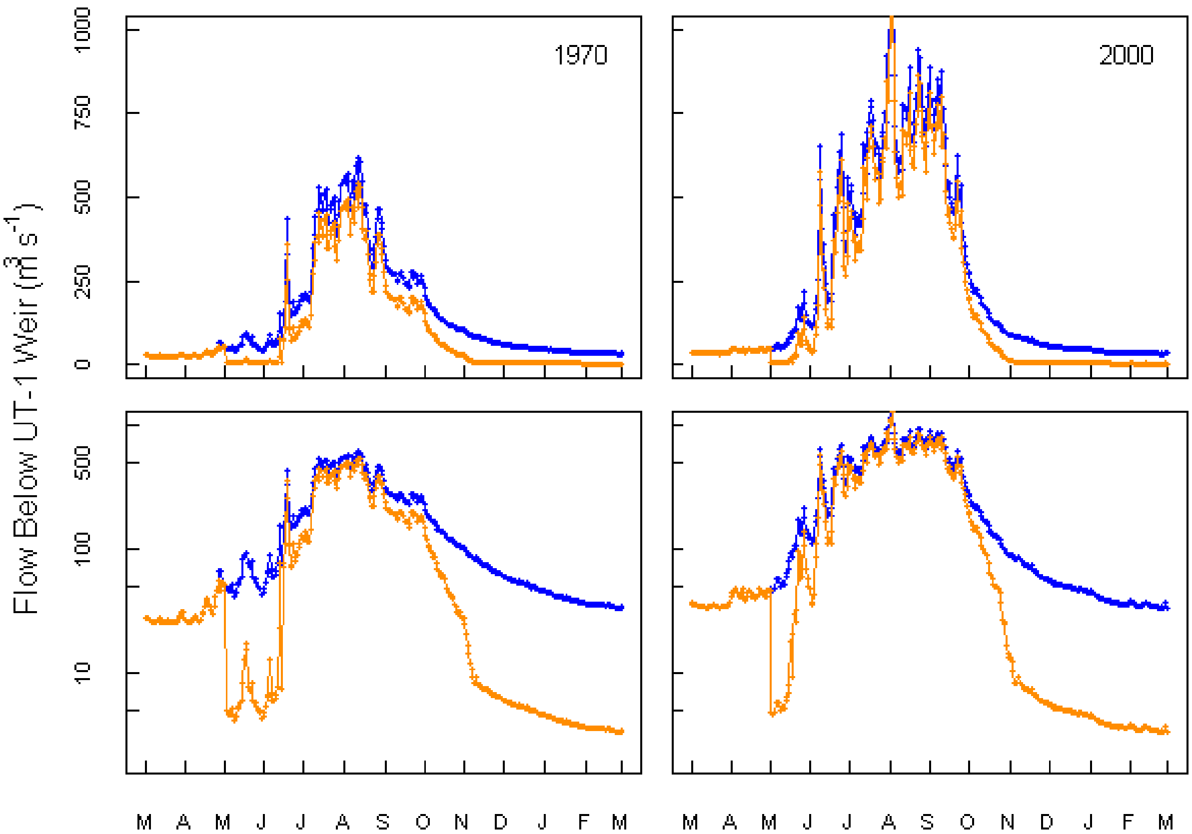


Figure 5-5: Daily flows for representative low-flow (1970) and high-flow (2000) under unimpaired (blue) and under the **50% instream flow scenario** (orange) in March and April. Upper graphs use a linear vertical scale which captures the extreme flows of the monsoon. Lower graphs show the same data with a logarithmic scale to show greater detail outside the monsoon period.

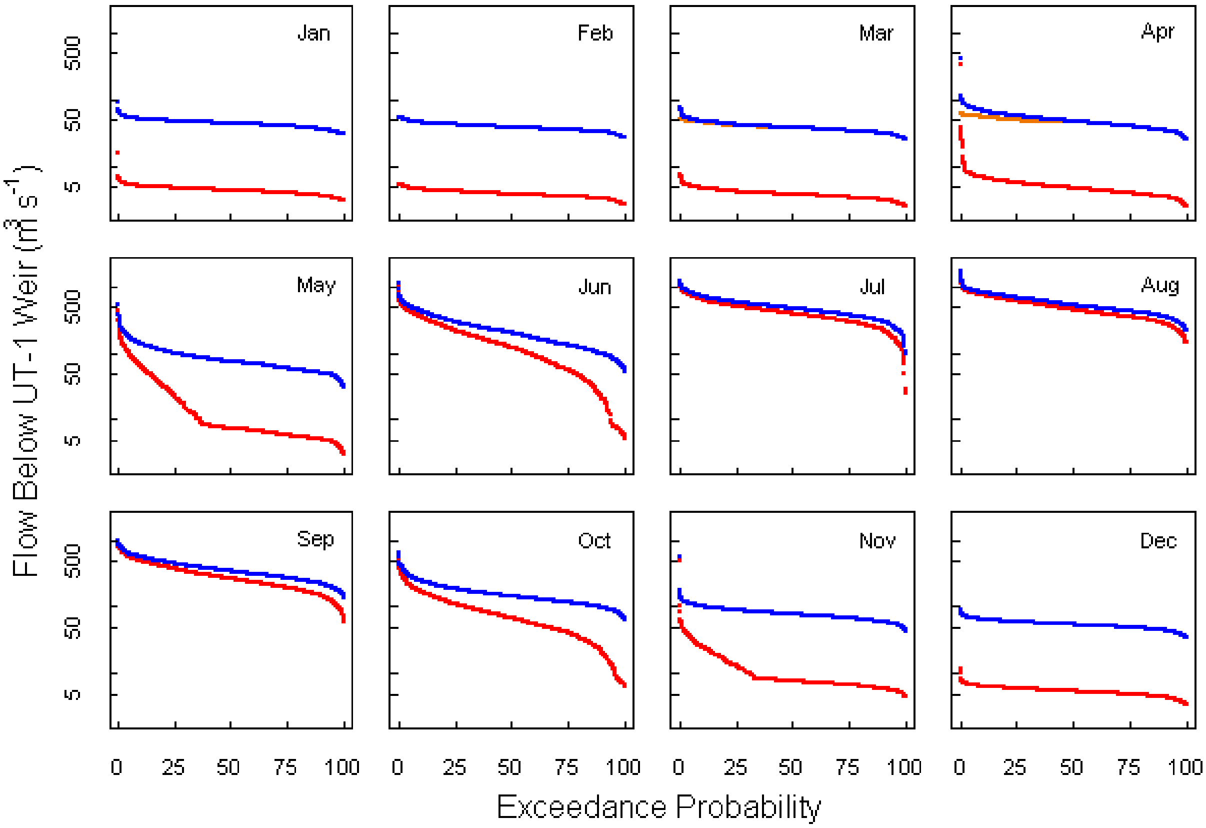


Figure 5-6: Monthly exceedance plots showing the distribution of baseline 1967-2010 historical discharge below the UT-1 weir (upper blue points), compared to the residual flow (lower red points) using the DK (2011b) management rule. The orange points visible just below the blue points in the March and April graphs show the flow alteration resulting from a scenario which implements a minimum instream flow of 50% for March and April. The y-axis has been transformed to a logarithmic scale because of the very high range of flow.

5.4 Assessment with IHA Metrics

In addition to the analysis of hydrographs provided above, the design flow scenario and the 50% and 80% scenarios were compared using the IHA software (Indicators of Hydrologic Alteration; Richter *et al.* 1996).[6] This software computes a standard set of 81 non-parametric statistics; flow measures which are computed for the unimpaired base flow and each scenario. These results are provided in Annex 2 and agree very closely with the flow characteristics of the scenarios described already, namely:

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[6] Version 7.1.0.10. © The Nature Conservancy. http://www.conservationgateway.org/ConservationPractices/Freshwater/EnvironmentalFlows/MethodsandTools/IndicatorsofHydrologicAlteration/Pages/IHA-Software-Download.aspx

1. The overall flow metrics (*e.g.* monthly minima, maxima, medians, flow ranges over scales of 3 to 90 days, timing of peaks) are nearly identical across all scenarios, apart from obvious differences in March and April flow in the 50% and 80% scenarios.
2. As expected under the design scenario, flow regimes are typically altered by 90% up to a maximum reduction of 76 $m^3 s^{-1}$. For example, if peak non-diverted flow in the baseline unimpaired flow case is 35 $m^3 s^{-1}$, flow in the diversion reach in that scenario will be 90% lower at 3.5 $m^3 s^{-1}$.
3. As a simple consequence of the typical 90% diversion in unimpaired flow during most months, upward and downward daily ramping rates are lower in all scenarios,

In conclusion, analysis of the scenarios using IHA software has provided confirmation of the analysis of the hydrographs presented earlier, along with the insight that ramping rates in all scenarios are reduced (less flashy) as a simple consequence of the diversion of flow for hydropower production.

5.5 Power under Design & Environmental Flow Scenarios

Power generation implications for the two scenarios of increased environmental flow described in Section 5.3 were assessed using the power generation model foreseen for UT-1 (see Annex 3). Daily power generation for the 50% and 80% March-April instream flow scenarios was calculated and compared to the design flow daily power production estimates. These are summarized in Table 5-3 and Table 5-4, and show that the two scenarios which provide the highest (80%) minimum instream flow during March or April each reduce expected annual power production by about 4.9% relative to the design scenario. A combined scenario which provides 50% or 80% minimum instream flow *over the two months* lowers average annual power production by about 10.3% and 10.9%, respectively. These scenarios are not prescriptive, but provide useful information about the potential cost (in lost power generation) of meeting a given minimum instream flow objective.

It should be emphasized that the Project design already includes a 5% loss of annual power due to maintenance operations. The two environmental flows scenarios considered in this analysis have not taken into account this power loss due to maintenance operations; potentially these annual activities could be timed to combine with the increased environmental flow needs during the upstream migration period, reducing the lost power generation capacity.

Table 5-3: Modeled power generation estimates under the design flow and the two environmental flow scenarios (50% or 80% of the unimpaired flow) explored in the sensitivity analysis. Cells shaded in green indicate the reduced monthly power values during the months when increased environmental flows would be released.

Environmental Flow Scenario		Average Monthly Power Production (GWh)												Average Annual generation (GWh)	Power reduction (%)
		J	F	M	A	M	J	J	A	S	O	N	D		
Design (10%)[1]		85.18	67.87	74.48	91.97	136.04	153.94	160.22	160.22	155.05	159.78	138.32	106.24	1489.31	0.0%
50%	M+A	85.18	67.87	**2.60**	**10.63**	136.04	153.94	160.22	160.22	155.05	159.78	138.32	106.24	1336.09	10.3%
	Mar	85.18	67.87	**2.60**	91.97	136.04	153.94	160.22	160.22	155.05	159.78	138.32	106.24	1417.43	4.8%
	Apr	85.18	67.87	74.48	**10.63**	136.04	153.94	160.22	160.22	155.05	159.78	138.32	106.24	1407.97	5.5%
80%	M+A	85.18	67.87	**0.99**	**3.64**	136.04	153.94	160.22	160.22	155.05	159.78	138.32	106.24	1327.49	10.9%
	Mar	85.18	67.87	**0.99**	91.97	136.04	153.94	160.22	160.22	155.05	159.78	138.32	106.24	1415.82	4.9%
	Apr	85.18	67.87	74.48	**3.64**	136.04	153.94	160.22	160.22	155.05	159.78	138.32	106.24	1400.98	5.9%

(4) Currently proposed environmental flow rule: release of a minimum of 10% of the mean monthly flow

Table 5-4: Inter-annual variation in predicted power generation under the design and the two environmental flow scenarios (50% or 80% of unimpaired flow) according to flow percentiles

	Annual Power Production (GWh)				
	Environmental Flow Scenario				
	DK	March		April	
	10%	50%	80%	50%	80%
Annual Total	**1,489**	**1,417**	**1,416**	**1,408**	**1,401**
Relative	1.000	0.952	0.951	0.945	0.941
Percentile					
0%	1,332	1,275	1,275	1,269	1,269
25%	1,451	1,386	1,386	1,370	1,370
50%	1,503	1,431	1,430	1,421	1,414
75%	1,536	1,456	1,455	1,449	1,437
100%	1,612	1,538	1,538	1,547	1,527

6 Summary and Recommendations

6.1 Summary

Once in operation, the UT-1 Project will create a flow-reduced segment of about 11 km along the diversion reach; from the intake site to the tailrace. According to the currently proposed operational rules, a minimum of 10% of the mean monthly flow (consistent with Nepal regulatory requirements) will be released as environmental flow. Impacts on aquatic ecology and habitats are therefore expected to occur within the 11-km diversion reach as well as in the downstream and upstream portions of the Trishuli River near the project site.

Potential impacts have been identified using a streamlined Impact Hypothesis Framework (Section 3). This framework identifies the following impacts are likely significant as a result of the construction and operation of the UT-1 Project:

1. *The weir will impair the passage of migratory fish, resulting in a barrier effect that could change in composition and abundance of species upstream/downstream of the weir.*

2. *Fish will be entrained in the penstock and/or stranded in the spillway, resulting in the impairment of downstream migration and potential changes in composition and abundance of species upstream/downstream of the weir.*

3. *Changes to the pattern of flow will change the timing, growth and abundance of fishes within the diversion reach.*

The impacts identified above could compromise the availability and quality of the aquatic habitat and the viability of the local population of snow trout (*Schizothorax richardsonii).* A review of the literature and recent fish survey in the project area indicate that *Schizothorax richardsonii* is the most relevant indicator fish species due to its abundance, migratory and spawning behaviors, and the fact that is fished for non-commercial purposes by local communities. The ecology of *S. richardsonii* is similar to that of other cold-water and high-mountain fish species in the Himalayan region and, therefore, this species can act as a proxy for a several species.

During the 2013-2014 aquatic baseline survey, field observation of female gonads of the captured specimens of *Schizothorax richardsonii* showed presence of ovaries with mature eggs starting from July to February. No eggs were found during the months of March and April and immature ova were observed in the months of May and June. These observations suggest that spawning in the project area occurs from March to May, before the monsoon season.

However, it should be noted that there are material knowledge gaps regarding the ecology of *S. richardsonii*, especially the exact timing and location of spawning and its migratory range. Given the existing knowledge gaps identified in this assessment, the environmental flows recommendations provided are highly speculative and further monitoring is required to gather critical information. Section 6.2 addresses these knowledge gaps.

This report uses a hydrology-based methodological approach as a recognized and widely accepted proxy for detailed habitat and ecological knowledge. In order to preserve ecosystem function, adopting an internationally recognized presumptive flow standard (Richter *et al.* 2012) is recommended as an environmental flow rule for analysis purposes. A final operational environmental flows regime will need to be developed once the key knowledge gaps have been filled in.Based on partial knowledge of the migratory patterns and habitat requirements of *S. richardsonii*, ***March-April is identified as the most critical period due to the occurrence of upstream migration and spawning. Increased environmental flow levels during this time will likely be required to facilitate the migration and spawning of the local snow trout population***. This potential requirement is examined through the sensitivity analysis of impacts to power generation for increased environmental flow regimes (50% and 80% of unimpaired flow) within those two months, in addition to the original design of 10% of unimpaired flow during the other months. Annual power production would be reduced by about 5% for each month (March and April) if the most conservative (80%) environmental flow is maintained. This would have significant impacts on the power generation scheme.

Environment flow assumptions presented in this report are based on historical (1967-2010) daily flow data from Betrawati station, located approximately 14 km downstream of the Project. The historic hydrological patterns (*e.g.*, Figure 2-1 and Figure 2-2) do not take into account climate change, and therefore may not provide accurate estimates of future regional and watershed hydrology. For example, the glaciers which feed the Ganges River are in decline regionally, due to recent warming and changes in monsoon patterns.

6.2 Recommendations

The project is likely to result in impacts on the aquatic ecology and habitats within the 11-km diversion reach as well as in the downstream and upstream portions of the Trishuli River near the project site. The local snow trout (*Schizothorax richardsonii*) has been chosen as the key indicator species. Based on the analysis presented in this report and the knowledge gaps that have been identified, the following are recommendations for the Project:

i. ***Environmental Flow Management Plan (EFMP):*** An EFMP should be developed to address current and future ecological knowledge gaps and to maintain viable fish populations during operations. See Section 7 for more details.

ii. ***Mitigation of impacts on aquatic habitats:*** Three key impacts have been identified as likely for the Upper Trishuli-1 Project: the barrier effect created by the dam, the risk of entrainment in the penstock, and the alteration of the hydrological regime in the diversion reach. These effects can reduce and/or degrade the aquatic habitat available to key species; interfere with their movement and migratory patterns; restrict the access to key habitats; and potentially affect the abundance and distribution of key species. Three mitigation measures (i.e. release of environmental flows, maintenance of spawning grounds, and fish screens at the intake) are likely to be required to maintain a viable population of *S. richarsonii* in the diversion reach. Additional measures may be required to mitigate the barrier effect. It should be noted that, considering the current and potential hydropower development in the basin, these impacts are likely to compound with those of other hydropower sponsors at the watershed scale. NWEDC should use best efforts to engage with other hydropower sponsors or other relevant stakeholders to explore coordinated monitoring and mitigation options.

7 Terms of Reference: Environmental Flows Management Plan

7.1 Goals of the EFMP

In order for the UT-1 Project to be constructed and operated in accordance with the IFC Performance Standards, an Environmental Flow Management Plan (EFMP) is needed to ensure the following goals:

- Guarantee that environmental flows are managed in a way that maintains the key ecological functions and viable aquatic habitats (i.e. viable *Schizothorax richardsonii* population) in the diversion reach;
- Address the existing knowledge gaps on aquatic habitats in the Project area; most notably the life cycle and migration patterns of the predominant snow trout species *Schizothorax richardsonii; and*
- Provide mitigation solutions for the impacts of hydrological alteration associated to the Project operation.

7.2 Approach and methodology

The EFMP for the Upper Trishuli-1 Project will need to include the following key elements, described in more detailed in the following sections:

- **Complementary Aquatic Baseline**: Additional studies and monitoring are required to fill in existing key ecological knowledge gaps.
- **Definition of Environmental Flow Rules**: In a context of uncertainty and lack of key information, an environmental flow range up to 80% of the unimpaired flow has been suggested as an interim precautionary flow rule. It is expected that final operational rules will be defined in an adaptive way based on additional information and the response of the aquatic environment to different flow levels.
- **Mitigation Program**: Potential impacts during the operation of the UT-1 Project include: degradation and/or loss of aquatic habitat due to reduced flow in the diversion reach; impaired upstream and downstream migration due to the barrier effect of the dam; and risk of fish entrainment. These potential impacts need to be quantified and if necessary adequately mitigated for.
- **Operations Monitoring Program**: Monitoring activities on key indicators are required to assess the Project's impacts on aquatic habitats and the effectiveness of the migration measures.
- **Organization and Capacity**: The management of the EFMP will need to be integrated within the overall management framework of the Project and specific personnel and other resources will need to assign for EFMP implementation.

- **Stakeholders Consultation**: Given the potential impacts on other water and river users, an *Environmental Flows Stakeholder Committee* incorporating key stakeholders will need to be created.
- **Regional collaboration**: The current state of hydropower development in the Trishuli watershed results in cumulative impacts on the aquatic environment from the multiple hydropower facilities. In this context, NWEDC should use its best efforts to engage and cooperate with regional mitigation or watershed management initiatives.
- **Reporting**: Information generated during the implementation of the EFMP will need to be recorded and disseminated to relevant parties.
- **Schedule of implementation**: A schedule for the implementation of the various activities under the EFMP needs to be defined.

The nature of the EFMP implies that the different activities/contents will be developed in an iterative way and multiple feedbacks are expected throughout the process. Adoption of an **Adaptive Management** framework (see Annex 4) is recommended as an efficient and scientifically credible process to resolve knowledge gaps, including uncertainty over best flow management practices, effective methods of habitat enhancement and implementation of other mitigation measures.

An Adaptive Management approach is consistent with IFC Performance Standard 6 which states that: "Given the complexity in predicting project impacts on biodiversity and ecosystem services over the long term, the client should adopt a practice of adaptive management in which the implementation of mitigation and management measures are responsive to changing conditions and the results of monitoring throughout the project's lifecycle".

Developing an EFMP that follows an Adaptive Management approach will provide the Project with a decision making mechanism that will be flexible to address new and unanticipated concerns which emerge from new knowledge, including issues which are not yet well understood which may not become evident for several years.

7.3 Complementary Aquatic Baseline

Additional studies and monitoring activities are required in order to close key knowledge gaps and to develop an EFMP consistent with international lender requirements, including the IFC Performance Standards.

7.3.1 Fish Migration Studies

Based on the best available knowledge, the key indicator species, *S. richardsonii*, migrates upstream during March and April (Table 4-2) to spawn. The timing and range of this migration needs to be verified and made more precise so that potential system operations impacts can be understood and mitigated so as to have the least impact on migration. Mark-recapture tagging studies at current sampling sites (see Figure 4-3 for location of NESS aquatic survey sampling sites) with resampling during this 8 week migration period are the best option for assessing the migration patterns of snow trout. Ideally, migration studies should monitor the fish during the upstream (March-April) and downstream (October-November) migration periods, in order to confirm that *S. richardsonii* can complete its annual cycle. Information gained from this study will allow a more precise estimate of the timing of the spawning period, enable a better assessment of likely impacts, and assist in the development of mitigation measures.

7.3.2 Habitat Inventory Studies

S. richardsonii are known to prefer gravel/pebble substrates for spawning (Table 4-2). It is presumed that spawning occurs in the confluence of the tributary streams and the Trishuli River, where presence of gravel substrates and low flow velocities are expected. Based on this assumption a preliminary GIS analysis identified 21 potential spawning locations within the diversion reach plus other 60 locations situated downstream and upstream of the diversion reach over a 15 km stretch (see Figure 3.3).

An inventory of these potential spawning habitats should be made for the length of the reduced flow reach, adding an additional inventory of 5 km upstream and 5 km downstream to provide context for the diversion-reach inventory. This information will be needed to provide a baseline pre-project assessment of spawning habitat (i.e. type, quality and quantity).

This habitat will need to be characterized, quantified and mapped as modified, natural, or critical habitat in accordance with IFC Performance Standard 6 requirements. A pre-operational habitat inventory should be followed by an operational survey to evaluate the Project's effects on spawning habitat.

7.3.3 Aquatic Habitat Monitoring

Current monthly sampling is beginning to provide baseline information about abiotic and biotic conditions at sampling sites along the reduced flow reach. Since the inception of the sampling program it has become clearer that *S. richardsonii* is the dominant fish species present in the river. The existing monthly monitoring program at current sampling sites, including ***water quality, aquatic habitat*** (i.e. physical characteristics, such as wetted width, and productivity, especially periphyton and macro-invertebrates)***, and fish***, should be maintained and extended for the next year (i.e. pre-operation), to provide a longer baseline of pre-project biotic and abiotic conditions. If monthly sampling discovers any additional fish species or key indicator invertebrates, they should be considered for their potential ecological importance and included in the monitoring program. All fish should be measured and released live, if possible. Monitoring should include the recording of tagged fish by location, to integrate with Section 7.2.

7.3.4 Stream channel morphology

As a result of modifying stream flow, hydroelectric projects have the potential to impact channel stability, channel geomorphology, and sediment transport and deposition. These impacts may occur both upstream and downstream of the intake, within the head pond and diversion channel, respectively, as well as below the powerhouse. Modifications to stream channel morphology may directly or indirectly alter physical habitats used by fish. the assessment will consider project effects on stream morphology in the diversion section, downstream of the powerhouse, and upstream of the intake where the creation of a head pond has the potential to affect sediment storage and transport and thus affect sediment transfer to downstream reaches. Within each of these locations, a number of transects should be established to define the baseline representative profile against which to monitor morphological change. A minimum of five transects should be established in the diversion channel, while a minimum of two transects should be located in each of the upstream and downstream sections (Lewis *et al*. 2012).

7.4 Definition of Environmental Flow Rules

Even with a more robust understanding of the likely ecological impacts, and the possible addition of other indicator species, it appears likely that maintenance of adequate flow will remain a key part of supporting a healthy ecosystem without habitat loss or degradation of ecosystem functions.

This analysis concludes that: (i) *an environmental flow release of 10% of the mean monthly flow during May to February is likely sufficient for in-stream ecological needs*; and (ii) *additional flow releases may be required in the low flow periods of March and April when migration and spawning of S. richardsonii take place*.

The final schedule of environmental flows releases (e.g. how many weeks within the March-April period will require increased flows) will need to be determined in a collaborative way including inputs from the engineering team, fish biologists, and local stakeholders (i.e. local water uses), and incorporate the results of the additional studies and the monitoring program, especially in terms of time of occurrence and duration of the migration of *S. richardsonii*. In terms of maintaining the geomorphological characteristics of the river, regular releases of flushing flows are found to maintain quality of spawning gravel by scouring fine sediments away (Gubhaju 2002).

As the additional studies and monitoring activities (Sections 7.1, 7.2 and 7.3) included in this EFMP progress, an Adaptive Management approach should be followed with adjustments in the timing and quantity of environmental flows as required.

7.5 Mitigation measures

Mitigation measures will need to be developed to compensate for the Project's impacts on aquatic habitats (loss of habitat, barrier effect and fish entrainment). The overall goal of these mitigation measures should be to maintain a viable population of *S. richardsonii* in the diversion reach, where the alterations to the natural flow regime could cause a reduction in the availability and quality of aquatic habitat, as well as internal mobility and access to spawning grounds.

The following mitigation measures are required to maintain viable populations of *S. richardsonii* in the diversion reach:

- Release of environmental flows
- Maintenance of spawning grounds
- Screens and fish exclusion devices

The weir is likely to create an impassible barrier for upstream migration during the dry period. If critical spawning areas become inaccessible for *S. richardsonii* after the construction of the weir the completion of the life cycle and, therefore, the long-term viability of the local snow trout population could be compromised. In this occurs, the mitigation measures mentioned above will be insufficient and the barrier effect of the weir will need to be addressed through one or a combination of the following measures:

- Fish hatchery and stocking
- Fish passes
- Trapping and hauling

The following sections discuss the required and additional mitigation measures for the UT-1 Project.

7.5.1 Release of environmental flows

Reduced flow downstream of the intake, especially during the dry season, will have an effect on the aquatic habitats in the diversion reach. This effect is local and can be overcome to some extent by releasing compensation flow downstream. Adequate compensation flow in accordance with the environmental flow rules, as defined in Section 7.4, will need to be released into the diversion reach to maintain aquatic habitats in this river stretch.

7.5.2 Maintenance of spawning grounds

Once the habitat inventory is completed (see 7.2 above), measures to avoid, minimize, and mitigate impacts to spawning habitat will be required to be developed. For example, where there are likely impacts to natural spawning habitats then mitigation measures will be required to achieve no net loss of such habitat, as required by the IFC Performance Standards. Spawning habitat enhancement measures typically implemented in Nepal include the following (Gubhaju 2002):

- Depositing gravel to increase the spawning habitat.
- Manipulating angular and large boulders to create pools for spawning and as an escape cover for resident fish during low water levels.
- Using large boulders to alter the flow pattern downstream.

- Keeping gravel and boulders together to create spawning riffles to attract resident stock to rapids.
- Releasing flushing discharge to re-water exposed gravel beds to maintain spawning gravel quality.
- Enhancing the habitat by tree planting to increase shelter cover, shade and drift food.

7.5.3 Screens and fish exclusion devices

Entrainment of out-migrants is a major concern because the river will be 90% diverted during the dry season. Entrapment of fish is a critical issue and some provision should be made to protect the fish against entrapment and impingement. Installation of appropriate screen devices at the intake will divert the fish from water intakes. Ideally, fish bypass facilities should be installed.

7.5.4 Mitigation of barrier effect

The diversion dam will physically block the upstream and downstream migration of fish resulting in reduction in spawning success due to loss of habitat and ultimately reduction of fish stocks. Evidence of these effects has been observed in the rivers Andhikhola, Marsyangdi, Trishuli and other hydropower or irrigation dams of the country (Upadhaya and Shrestha 2002), where the lack of mitigation measures for this effect has led to the endangerment of indigenous fish species (Gubhaju 2002). The following measures can help with the mitigation of the barrier effect. One of the following options will be required for the UT-1 Project.

Fish hatchery and stocking

At present in Nepal (Gubhaju 2002), preference is given to maintenance of spawning grounds and fish hatcheries as a means of maintaining the fish stocks and mitigating the barrier effect of the dam.

Hatcheries should produce seed of the important native fish species; snow trout in the case of the UT-1 Project. Minimal area requirements for the hatchery ponds would be approximately 3 hectares, however double that amount of space is preferred. Ideally, the sponsor should engage in regional collaboration with other hydropower sponsors in the Trishuli watershed to develop coordinated breeding and stocking programs and reduce the costs.

There are precedents of successful establishment of cold fish hatcheries in Nepal: reservoir cage culture experiences have been reported for the Trishuli and the Kulekhani reservoirs (Upadhaya and Shrestha 2002); and a multi-species hatchery breeds and stocks indigenous fish species (Tor putitora, Schizothorax progastus, Labeo dero, Neolissocheilus hexagonolepis) for the Kali Gandaki-A Hydropower Project7, where the aquatic habitat conditions are similar to those of the Trishuli River.

In particular in the case of snow trout species (*Schizothorax plagiostomus* and *Schizothoraichthys progastus*), artificial breeding has been practiced in the Fisheries Research Centre Trishuli since 1971 but the hatching rate is low (higher, around 50%, during the October-November period) and mortality of alevins is still high (>50%). One of the main impediments for the successful breeding of snow trout seems to be their specialized feeding habit and mouth structure (i.e. snow trout are phytofagus and feed predominantly on algae by scraping on the river bottom) for which no commercial feed technology has been developed yet (Rai *et al*. 2002).

Fish passes

This type of measure refers to any fish passage devices that allow fish to go around the weir (i.e. fish ladder, ramps). These structures have been designed mostly for fish species in temperate regions and the experience to date with fish passes in Nepal has been unsatisfactory (Gubhaju 2002). The fish pass needs to be tested for the known fish species migratory behavior and monitored by fishery specialists.

Examples of fish passes developed for indigenous fish species in Nepal, include the case of the fish ladder built at Andhi Khola[8], which has been designed to allow the passage of *Tor putitora*, *Neolissocheilus hexagonolepis*, and *Schizothorax progastus*. The latter has a similar migration patter to *S. richardsonii*.

Trapping and hauling

This involves trapping of fish below the dam and transporting them to the reservoir or further upstream to maintain fish diversity and gene pool. This option is labor intensive, prone to poaching by handlers and stressful to fish which increases their mortality. It also needs an appropriate location: facilities have to be designed at the earliest possible stage and well incorporated into the project - a later addition may be problematic or not possible at all (Gubhaju 2002).

The diversion dam is the most suitable place for establishing a permanent trapping station as migrating fish congregate either upstream or downstream of the dam (Upadhaya and Shrestha 2002).

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[7] Breeding of cold water indigenous fish in Nepal: http://fishconsult.org/?p=1703

[8] Fish ladder in Andhi Khola: http://fishconsult.org/?p=1732&relatedposts_exclude=1703

7.6 Operations Monitoring Program

Monitoring activities in the Project area need to be expanded into the operational phase in order to meet the following goals:

1. Evaluate the relative success of mitigation and compensation measures (see Section 7.5) designed to minimize or offset environmental impacts, and;
2. Allow for improvement of Project management through the evaluation of project effects and the integration of adaptive learning.

The specific design of the monitoring program will have to be agreed in accordance with the engineering team, biologists and aquatic ecologists, as well as the local stakeholders. The following sections suggest the main parameters that should be included in the monitoring program.

7.6.1 Instream flow

As previously discussed, flow modification and alteration influence the productive capacity of aquatic habitat. Hydrometric monitoring of stream discharge in the diversion reach is needed to measure compliance with the environmental flows rules. Ideally, accurate, real-time **flow data** should be monitored through the life of the project to provide measures of environmental conditions that will assist in the interpretation of changes in biological components of the monitoring program.

7.6.2 Aquatic habitat

The pre-operational monitoring of aquatic should be followed by an operational monitoring program, typically focusing on those indicators or key species that are expected to be most affected by the Project (i.e. a subset of the baseline indicators). Periphyton and macro-invertabrates, as main sources of food of *S. richarsonii*, should be included in the operational indicators. Fish surveys should be conducted at the same locations and following the same methods as the baseline monitoring.

This survey should also include the monitoring of the spawning grounds identified within the project area of influence as well as the habitat characteristics (i.e. wetted width, habitat type) at the same five locations used during the baseline monitoring.

The length (usually a minimum of three years) and scope of the operational monitoring program will be determined based on the outcomes of the baseline survey. In the absence of regulatory or other monitoring requirements, relevant international references (Lewis *et al*. 2012) can help inform the monitoring design.

7.6.3 Impacts on other water/river uses

A number of water uses (i.e. domestic/recreational, irrigation and water mills) have been identified in the lower part of the diversion reach (see Figure 2.3). It has also been confirmed that non-commercial fishing is practiced in the area around the powerhouse. Fish is a complementary source of food for local communities.

These groups of water and river users need to be integrated in the *Environmental Flows Stakeholder Committee* and a monitoring protocol, specifically targeting the critical dry period, should be defined to assess the potential impacts that a reduction of flows in the diversion reach will have on these uses.

7.6.4 Monitoring of mitigation measures

Depending on the final mitigation measures to be adopted (Section 7.5) a series of variables and parameters will need to be covered by the monitoring program. For example:

Fish screens and/or fish pass: The condition of the screen and/or fish pass should be inspected on an annual basis prior to, and during, critical times such as the downstream migration of juvenile fish, or the upstream migration of spawning adults. Any factors that may impair, delay or block fish migration identified during these inspections need to be reported.

Mitigation of barrier effect: Fish surveys upstream and downstream of the dam are needed to assess potential changes in the population distribution that may relate to the barrier effect of the dam.

Compensation spawning habitat: Recreated spawning habitat of snow trout needs to be monitored to confirm its quality (e.g. substrate, vegetation cover, etc.) and effectiveness..

7.7 Organization and Capacity

There is a need to provide ongoing resources, in terms of qualified personnel and adequate funding, to the activities that will be implemented as part of the EFMP. The management of environmental flows should be integrated in overall environmental management framework for the Project and be one of the mandates of NWEDC's Environmental and Social Management Cell (ESMC). Responsibilities for the different activities under the EFMP (e.g. monitoring, mitigation, etc.) need to be identified, as well as the level of qualifications required for each of them.

7.8 Stakeholders Consultation Plan

An ***Environmental Flows Stakeholder Committee*** should be created, including representation from local communities, Langtang National Park and government representatives, the operator and an independent environmental specialist as proposed in the 2011 EIA (Jade Consult 2011).

As previously mentioned in Section 2, there are a number of water and river users that might be impacted by the Project that should be included in the Stakeholder Committee.

7.9 Regional Collaboration

The UT-1 Project is set within an area where multiple hydropower projects are in different stages of planning, construction and operation. The construction of multiple hydropower facilities in the Trishuli watershed is likely to result in the fragmentation of aquatic habitats by the compounding effect of a series of passage barriers; and in the deterioration of quality and/or loss of habitat in the river stretches under reduced flow, especially during the dry period. The Cumulative Impact Assessment of the Supplemental ESIA (Appendix D) includes an analysis of cumulative impacts on aquatic habitats.

In order to mitigate these cumulative impacts, there should be best efforts made to promote and participate in coordinated actions with other hydropower projects and other relevant stakeholders within the watershed to preserve aquatic habitats and target fish species (*e.g.*, fish ladders, catch and capture programs, hatcheries, *etc*.).

7.10 Reporting

Abundant information will be generated during the implementation of the EFMP. Information requirements and adequate mechanisms for recording and disseminating this information to relevant stakeholders (i.e. local communities, Langtang National Park authority, and government agencies) need to be identified early in the process.

7.11 Schedule of implementation

Once all the activities under the EFMP have been identified, a schedule of implementation will have to be defined taking into consideration the Project's construction and operations schedule and the seasonality of the aquatic habitats and flows. Some of the activities to be implemented may have critical pathways or windows of opportunity, and these key milestones need to be identified early in the planning process.

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Annex 1: Taxonomy of Fish Species in the Upper Trishuli

Inventories of resident and migratory fishes within the Trishuli River system are often complicated by the use of synonyms among scientific names, as well as a variety of local and English names. A cross-walk of species is names if provided in Table A1-1.

Table A1-1: Nomenclature of nineteen fish species recorded in the Upper Trishuli River.

Scientific Name	Older Synonym	Local Name	Common English Name
Acanthocobitis botia	*Noemacheilus botia*	Gadela	Mottled loach
Barilius barila		Faketa	
Barilius bendelisis		Fakata	
Barilius vagra		Fakata	
Channa gachua		Hile	Dwarf snakehead
Garra annandalei		Buduna	
Garra gotyla		Buduna	Stone roller
Glyptosterrum blythi		Tilkabre	
Glyptothorax pectinopterus		Kabre	Sucker catfish
Glyptothorax telchitta		Kabre	Sucker catfish
Labeo dero	*Bangana dero*	Gardi	Kalabans
Mastacembelus armatus		Kalo bam	Zig-zag eel
Neolissochilus hexagonolepis	*Acrossocheilus hexagonolepis*	Katle	Copper mahseer
Pseudecheneis sulcatus		Kabre	
Psilorhynchus pseudecheneis		Tite	Nepalese minnow, stone carp
Schistura beavani	*Noemacheilus beavani*	Gadela	Creek loach
Schizothorax progastus	*Schizothoraichthys progastus*	Chuchche asala	Snow trout
Schizothorax richardsonii		Buchche asala	Snow trout
Tor putitora		Mahseer	Golden mahseer

Source: Adapted from DOFD (2008).

Annex 2: Summary of IHA metrics

Table A2-1: The non-parametric IHA scorecard produced by IHA software is shown for the 45 year hydrological record (1966-2010). Base flow condition and 4 selected operating scenarios: (a) DK (2011); (b) March 75% minimum flow; (c) April 75% minimum flow and March 50% minimum flow combined with April 50% minimum flow. Differences between the Base scenario and the four operating scenarios are shown in blue. The four blue columns show the difference between each metric and its Base Scenario value. The great majority of values are either (a) identical; (b) are 10% of the base value, due to the 90% diversion rule in effect in most or all months; or (c) differ by 76 m3 s–1; the maximum design diversion.

	Base		DK 2011			March 80%			April 80%			March 50%, April 50%		
Normalization Factor	1		1		0	1		0	1		0	1		0
Mean annual flow	181.3		122.2		-59.1	125		-56.3	125.6		-55.7	128.1		-53.2
Non-Normalized Mean Flow	181.3		122.2		-59.1	125		-56.3	125.6		-55.7	128.1		-53.2
Annual C.V.	1.11		1.56		0.45	1.51		0.4	1.51		0.4	1.46		0.35
Flow predictability	0.74		0.64		-0.1	0.65		-0.09	0.65		-0.09	0.66		-0.08
Constancy/predictability	0.47		0.38		-0.09	0.33		-0.14	0.32		-0.15	0.31		-0.16
% of floods in 60d period	0.65		0.65		0	0.65		0	0.65		0	0.65		0
Flood-free season	159		159		0	159		0	159		0	159		0
Parameter Group 1 (Month)	**Median**	**Dispersion**	**Median**	**Dispersion**	**Difference**	**Median**	**Dispersion**	**Difference**	**Median**	**Dispersion**	**Difference**	**Median**	**Dispersion**	**Difference**
March	37.59	0.1695	3.759	0.1695	-33.831	37.32	0.1671	-0.27	3.759	0.1695	-33.831	37.32	0.1611	-0.27
April	47.1	0.2138	4.71	0.2138	-42.39	4.71	0.2138	-42.39	46.92	0.25	-0.18	46.72	0.1517	-0.38
May	73.56	0.4055	7.356	1.269	-66.204	7.356	1.269	-66.204	7.356	1.269	-66.204	7.356	1.269	-66.204
June	209.5	0.5771	133.5	0.9057	-76	133.5	0.9057	-76	133.5	0.9057	-76	133.5	0.9057	-76
July	463.8	0.3907	387.8	0.4673	-76	387.8	0.4673	-76	387.8	0.4673	-76	387.8	0.4673	-76
August	497.9	0.4784	421.9	0.5646	-76	421.9	0.5646	-76	421.9	0.5646	-76	421.9	0.5646	-76
September	325.2	0.4559	249.2	0.5949	-76	249.2	0.5949	-76	249.2	0.5949	-76	249.2	0.5949	-76
October	139.9	0.3301	63.95	0.7225	-75.95	63.95	0.7225	-75.95	63.95	0.7225	-75.95	63.95	0.7225	-75.95
November	77.06	0.1935	7.706	0.3012	-69.354	7.706	0.3012	-69.354	7.706	0.3012	-69.354	7.706	0.3012	-69.354
December	55.44	0.1675	5.544	0.1675	-49.896	5.544	0.1675	-49.896	5.544	0.1675	-49.896	5.544	0.1675	-49.896
January	43.06	0.1531	4.306	0.1531	-38.754	4.306	0.1531	-38.754	4.306	0.1531	-38.754	4.306	0.1531	-38.754
February	37.68	0.1774	3.768	0.1774	-33.912	3.768	0.1774	-33.912	3.768	0.1774	-33.912	3.768	0.1774	-33.912
Parameter Group 2 (Min/Max)	Median	Dispersion	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**
1-day minimum	32.83	0.1298	3.283	0.1298	-29.547	3.364	0.1467	-29.466	3.319	0.1284	-29.511	3.49	0.1799	-29.34
3-day minimum	33.19	0.1284	3.319	0.1284	-29.871	3.385	0.1484	-29.805	3.349	0.1272	-29.841	3.558	0.184	-29.632
7-day minimum	33.47	0.1279	3.347	0.1279	-30.123	3.442	0.1672	-30.028	3.371	0.127	-30.099	3.608	0.1817	-29.862
30-day minimum	35.96	0.1401	3.596	0.1401	-32.364	3.7	0.1806	-32.26	3.606	0.1416	-32.354	3.773	0.1807	-32.187
90-day minimum	46.65	0.1569	4.665	0.1415	-41.985	4.7	0.1499	-41.95	4.674	0.1475	-41.976	4.7	0.1499	-41.95
1-day maximum	787.7	0.5649	711.7	0.6253	-76	711.7	0.6253	-76	711.7	0.6253	-76	711.7	0.6253	-76
3-day maximum	692	0.5022	616	0.5641	-76	616	0.5641	-76	616	0.5641	-76	616	0.5641	-76

7-day maximum	656.9	0.5199	580.9	0.5879	-76	580.9	0.5879	-76	580.9	0.5879	-76	580.9	0.5879	-76
30-day maximum	556.2	0.4733	480.2	0.5482	-76	480.2	0.5482	-76	480.2	0.5482	-76	480.2	0.5482	-76
90-day maximum	467.8	0.4314	391.8	0.5151	-76	391.8	0.5151	-76	391.8	0.5151	-76	391.8	0.5151	-76
Number of zero days	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Base flow index	0.1912	0.2749	0.02852	0.4043	-0.16268	0.02929	0.4339	-0.16191	0.02769	0.4133	-0.16351	0.02943	0.4458	-0.16177
Parameter Group 3 (Date)	Median	Dispersion	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**
Date of minimum	62	0.06831	62	0.06831	0	57	0.1189	-5	62	0.06557	0	54	0.03689	-8
Date of maximum	220	0.05464	220	0.05464	0	220	0.05464	0	220	0.05464	0	220	0.05464	0
Parameter Group 4 (Pulse)	Median	Dispersion	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**
Low pulse count	3	1	3	1	0	4	0.5	1	3	0.6667	0	3	1	0
Low pulse duration	7.5	3.333	7.5	3.333	0	11	1.432	3.5	18	2.792	10.5	9.75	6.346	2.25
High pulse count	3	1	3	1	0	3	1	0	3	1	0	3	1	0
High pulse duration	5.5	9.182	5.5	9.182	0	5.5	9.182	0	5.5	9.182	0	5.5	9.182	0
Low Pulse Threshold	45.84		4.58		-41.26	5.11		-40.73	4.88		-40.96	5.63		-40.21
High Pulse Threshold	267.3		191.3		-76	191.3		-76	191.3		-76	191.3		-76
Parameter Group 5 (Ramping)	Median	Dispersion	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**
Rise rate	7.267	0.5216	4.486	1.2	-2.781	4.685	1.053	-2.582	5.831	0.7357	-1.436	6.28	0.7143	-0.987
Fall rate	-3.409	-0.3224	-1.794	-1.171	1.615	-1.794	-1	1.615	-2.512	-0.752	0.897	-2.691	-0.6833	0.718
Number of reversals	119	0.2311	119	0.2311	0	119	0.2353	0	120	0.2208	1	119	0.2437	0
EFC Low Flows (Monthly Lows)	Median	Dispersion	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**
March Low Flow	40.01	0.1177	4.001	0.1177	-36.009	37.32	0.1671	-2.69	4.055	0.1173	-35.955	37.32	0.1611	-2.69
April Low Flow	49.83	0.1643	4.983	0.1643	-44.847	5.096	0.1554	-44.734	46.92	0.25	-2.91	46.72	0.1517	-3.11
May Low Flow	73.56	0.3994	7.356	1.263	-66.204	7.356	1.29	-66.204	7.356	1.263	-66.204	7.356	1.317	-66.204
June Low Flow	148.5	0.4094	72.47	0.8387	-76.03	72.47	0.8387	-76.03	72.47	0.8387	-76.03	72.47	0.8387	-76.03
July Low Flow	231.9	0.2089	155.9	0.3107	-76	155.9	0.3107	-76	155.9	0.3107	-76	155.9	0.3107	-76
August Low Flow	253.9	0.3083	177.9	0.3979	-76	177.9	0.3979	-76	177.9	0.3979	-76	177.9	0.3979	-76
September Low Flow	235.9	0.1407	159.9	0.2075	-76	159.9	0.2075	-76	159.9	0.2075	-76	159.9	0.2075	-76
October Low Flow	139.1	0.2984	63.05	0.6581	-76.05	63.05	0.6581	-76.05	63.05	0.6581	-76.05	63.05	0.6581	-76.05
November Low Flow	77.06	0.1935	7.706	0.3012	-69.354	7.706	0.3012	-69.354	7.706	0.3012	-69.354	7.706	0.3012	-69.354
December Low Flow	55.44	0.1675	5.544	0.1675	-49.896	5.544	0.1675	-49.896	5.544	0.1675	-49.896	5.544	0.161	-49.896
January Low Flow	43.62	0.1275	4.362	0.1275	-39.258	4.423	0.09026	-39.197	4.378	0.1148	-39.242	4.548	0.05917	-39.072
February Low Flow	40.23	0.09699	4.023	0.09699	-36.207	4.225	0.06635	-36.005	4.055	0.07522	-36.175	4.373	0.08	-35.857
EFC Parameters	Median	Dispersion	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**	Median	Dispersion	**Difference**
Extreme low peak	35.03	0.06754	3.503	0.06754	-31.527	3.723	0.1069	-31.307	3.548	0.1037	-31.482	3.615	0.1573	-31.415
Extreme low duration	7	1.714	7	1.714	0	7.25	1.69	0.25	8	3.563	1	19.25	1.838	12.25
Extreme low timing	77	0.09802	77	0.09802	0	72.75	0.1219	-4.25	74	0.08538	-3	49.25	0.0485	-27.75
Extreme low freq.	2	1.5	2	1.5	0	3	0.6667	1	2	1	0	2	0.5	0
High flow peak	356.8	0.4463	280.8	0.567	-76	280.8	0.567	-76	280.8	0.567	-76	280.8	0.567	-76

High flow duration	3	1.167	3	1.167	0	3	1.167	0	3	1.167	0	3	1.167	0
High flow timing	199.3	0.1844	199.3	0.1844	0	199.3	0.1844	0	199.3	0.1844	0	199.3	0.1844	0
High flow frequency	3	1.167	3	1.167	0	3	1.167	0	3	1.167	0	3	1.167	0
High flow rise rate	40.44	1.167	40.44	1.167	0	40.44	1.167	0	40.44	1.167	0	40.44	1.167	0
High flow fall rate	-44.1	-0.7882	-44.1	-0.7882	0	-44.1	-0.7882	0	-44.1	-0.7882	0	-44.1	-0.7882	0
Small Flood peak	1005	0.2938	928.8	0.3178	-76.2	928.8	0.3178	-76.2	928.8	0.3178	-76.2	928.8	0.3178	-76.2
Small Flood duration	98	0.2959	98	0.2959	0	98	0.2959	0	98	0.2959	0	98	0.2959	0
Small Flood timing	215	0.04918	215	0.04918	0	215	0.04918	0	215	0.04918	0	215	0.04918	0
Small Flood freq.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small Flood rise rate	16.51	0.891	16.51	0.891	0	16.51	0.891	0	16.51	0.891	0	16.51	0.891	0
Small Flood fall rate	-13.69	-0.6137	-13.69	-0.6137	0	-13.69	-0.6137	0	-13.69	-0.6137	0	-13.69	-0.6137	0
Large flood peak	1404	0.2316	1328	0.2449	-76	1328	0.2449	-76	1328	0.2449	-76	1328	0.2449	-76
Large flood duration	105.5	0.1445	105.5	0.1445	0	105.5	0.1445	0	105.5	0.1445	0	105.5	0.1445	0
Large flood timing	224.5	0.04303	224.5	0.04303	0	224.5	0.04303	0	224.5	0.04303	0	224.5	0.04303	0
Large flood freq.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large flood rise rate	23.13	0.5154	23.13	0.5154	0	23.13	0.5154	0	23.13	0.5154	0	23.13	0.5154	0
Large flood fall rate	-23.22	-0.3689	-23.22	-0.3689	0	-23.22	-0.3689	0	-23.22	-0.3689	0	-23.22	-0.3689	0
EFC low flow threshold:					0			0			0			0
EFC high flow threshold		267.3		191.3	0		191.3	0		191.3	0		191.3	0
EFC extreme low flow threshold		37.14		3.714	0		4.028	0		3.795	0		4.216	0
EFC small flood minimum peak flow		787.7		711.7	0		711.7	0		711.7	0		711.7	0
EFC large flood minimum peak flow		1245		1169	0		1169	0		1169	0		1169	0

Annex 3: Power Generation Model

The prosed operational flow rules (DK 2011b) were inferred from the average monthly flows. Based on these rules, the corresponding default monthly power generation were estimated (DK 2011b) by inferring the underlying relationship between flow and power produced at the turbines.

To allow the estimation of the consequences to power production from the alternative environmental flow scenarios described in Section 5.3, a reverse-engineering approach based on the design document is used, because the full set of parameters and assumptions for the governing hydraulic equations is not available. This relationship is shown in Figure A3-1, based on weir-adjusted daily Betrawati unimpaired flow, the flow scenarios described in Section 5.2 and 5.3 and the power estimates provided in DK (2011b) prior to adjusting for maintenance and infrastructure losses of 5.1%.

Due to the fact that the flow-power relationship is not linear and daily flow and power calculations are reported on a monthly basis, there are small variations in power produced for a given monthly flow. In addition to these non-linearities, it is not possible to infer from the monthly averages precisely how the turbines would be brought off- and on-line at very low flow. This uncertainty becomes apparent when the diverted flow drops below about 25 $m^3\ s^{-1}$. For simulation purposes we have assumed that the power produced at these low flows decline nearly linearly until the diverted flow reaches 12.7 $m^3 s^{-1}$, at which point the remaining single operating turbine would be taken off-line. Despite some uncertainties, a fairly clear relationship, based on a b-spline smoother (R Development Core Team 2013) emerges in Figure A3-1, with noticeable inflections in the profile taking place near 38 $m^3\ s^{-1}$ and 28 $m^3\ s^{-1}$. This relationship is potentially very useful, since it provides predictive ability to estimate power production under a variety of operational scenarios, in addition to replicating the estimates of the design scenario.

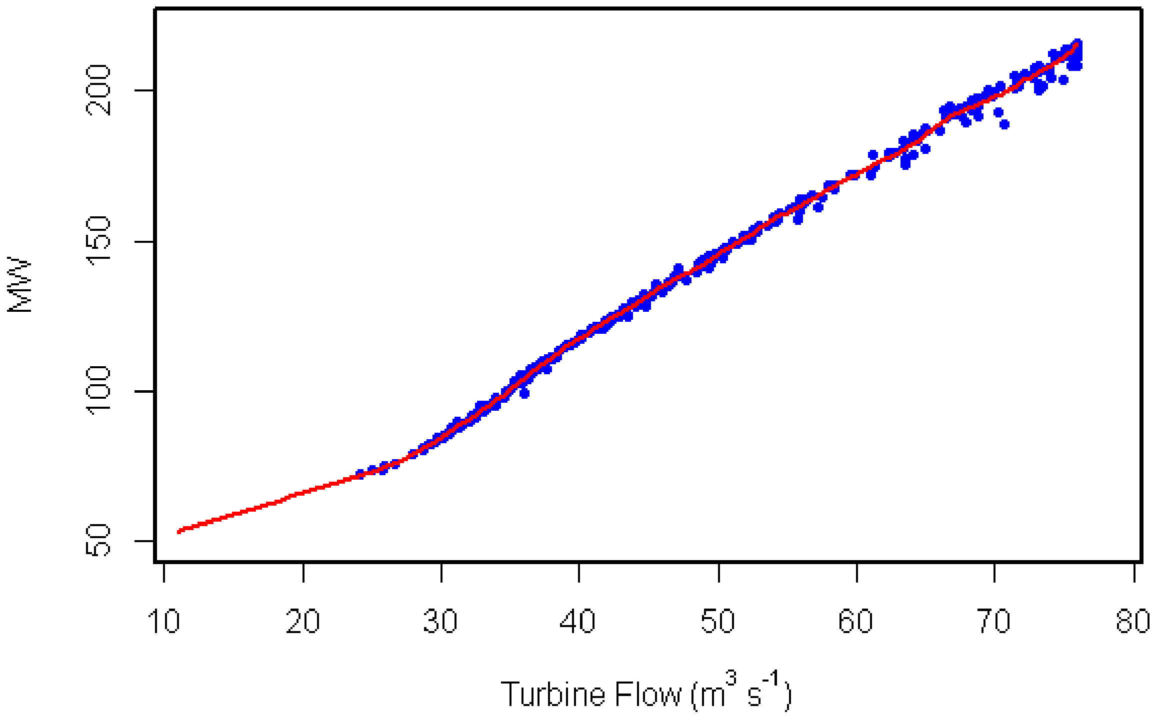

Figure A3-1: Power generation estimated as a function of diverted flow using average diverted flow and monthly power from the engineering design (DK 2011b). Power production has been converted from monthly total power (GWh) to instantaneous power (MW). The interpolated flow-power curve shown by the red line is created by a b-spline smoothing function and used to estimate daily generation under different operation scenarios.

To test the ability of the relationship shown in Figure A3-1 to predict monthly power production, this report applied it to the design flow and daily UT-1 diverted flow estimates over the 1967-2010 period, to see how well it reproduces the original monthly power generation estimates (DK 2011b). The difference between the model predictions and the original design power estimates are shown in Figure A3-2 as the residual difference between the DK (2011b) monthly estimates and the predictions of the smooth-line model. The model residuals are unbiased (μ = –0.01; SD = 1.067) over the entire range of diverted flow, with 95% of residuals within ±2.1 GWh (gigawatt-hours) for monthly power production. Figure A3-2 shows that residuals are highest and predictive power lowest around 140 GWh, which corresponds to the changing flow regime at the onset and end of the monsoon. In spite of this uncertainty, the model's freedom from bias makes it adequate to test alternative power generation scenarios.

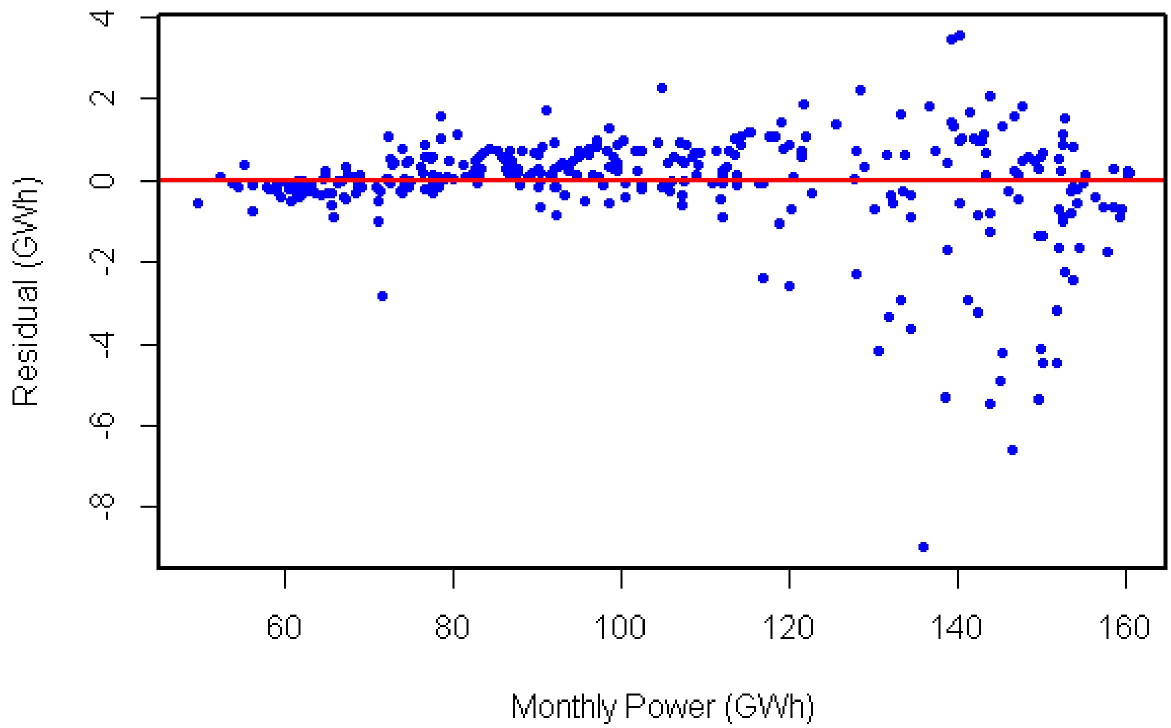

Figure A3-2: Residual error derived from the application of the Power-Flow relationship (Figure A3-1) to daily estimates of UT-1 diverted flow for over the 1967-2010 period, using the DK (2011b) system operation assumptions. The monthly estimates are unbiased, distributed fairly symmetrically around the horizontal red line (μ= –0.01, SD=1.067) with 95% of residuals found within 2.1 GWh of the DK power calculations. The region of greatest uncertainty falls around 140 GWh, which corresponds to the onset of the monsoon period, when power generation changes most rapidly.

Annex 4: Synopsis of Adaptive Management

The development of an Environmental Flow Management Plan (EFMP) requires an Adaptive Management (AM) approach. This is consistent with international lender requirements such as the IFC Performance Standards (PS). IFC PS6 for example states that: “Given the complexity in predicting project impacts on biodiversity and ecosystem services over the long term, the client should adopt a practice of adaptive management in which the implementation of mitigation and management measures are responsive to changing conditions and the results of monitoring throughout the project’s lifecycle”.

AM is a rigorous approach for learning through deliberately designing and applying management actions to maximize learning. AM involves synthesizing existing knowledge, exploring alternative actions, making explicit predictions of their outcomes, selecting one or more actions to implement, conducting monitoring and research to see if the actual outcomes match those predicted, and then using these results to learn and adjust future management and policy. This sequence is summarized in a six-step cycle:

Figure A4-1: Adaptive management cycle

AM is generally considered to exist in two forms:

- **Active** – In active AM, managers explicitly recognize in step 1 that they don’t know which actions are best, and then select two or more alternative activities to design and implement in steps 2 and 3. Monitoring and evaluation (steps 4 and 5) of each alternative helps to decide which was more effective in meeting objectives and thus leads to adjustments in management actions.

- **Passive** – In passive AM, alternatives are assessed in step 1 (assess), and one management action deemed best is designed and implemented in steps 2 and 3 (design and implement). Monitoring and evaluation (steps 4 and 5) then lead to appropriate adjustments (step 6).

It is the Passive form of AM that has relevance to the practice of environmental assessment and impact prediction.

Uncertainties are inherent in any prediction of impacts. Despite rigorous environmental assessments of any project, some critical uncertainties may remain with respect to the impact predictions. Critical uncertainties are those which when resolved may result in an impact either being worse or better than predicted, and if they are worse, may cause unacceptable impacts to valued environmental components. Resolving critical uncertainties could also result in a change in decisions about mitigations actions. When applying adaptive management to the assessment of pre-project impacts, the critical uncertainties arising from the environmental assessment are very explicitly identified for each valued environmental component. If these uncertainties cannot be resolved prior to the construction and operation of the project, resolving them will require the carefully designed collection and evaluation of monitoring data once the project is operational. Adaptive management, implemented in a very rigorous manner, provides a framework for learning what is needed to reduce these uncertainties during project operation and then implementing the appropriate mitigations (*e.g.* changes in timing and/or volume flow releases) if unacceptable impacts occur, or are expected, from project operation.

An expectation inherent in the application of adaptive management in this manner is that if monitoring results determine that unacceptable impacts are occurring, or are about to occur (*e.g.* if the trajectory of an indicator shows a downward trend), there are feasible mitigations that can be applied, and there is a regulatory authority with the means to require this (*e.g.* through a permit amendment if monitoring results indicate that impacts are worse than expected).

This type of project adjustment once it is operational can also work in the project's favor. For example, if monitoring results during project operation show that the impacts are less than expected, there may be an opportunity to increase operational capacity and still operate within acceptable limits of environmental change. Again, this could be formalized through an upward amendment of an operating permit (versus a downward amendment in the paragraph above). This too would require a very carefully designed monitoring program, otherwise downward trends in valued environmental components may occur, but not be observed.

Appendix E: Final Report