
TMT

CHAPTER 5:

VALUED ENVIRONMENTAL COMPONENT: AQUATIC HABITAT

Rationale for Screening

The impacts of hydropower development on aquatic biodiversity are well known and are summarized in IFC (2018a). In addition to barriers to fish migration and dispersal, hydropower projects may also alter downstream flow and sediment volumes, timing, predictability, and flow change rates, which, together with temperature, water clarity, and other water quality changes, can alter species composition and relative abundance, and can disrupt flow-related cues that trigger important fish life milestones such as migration or spawning.

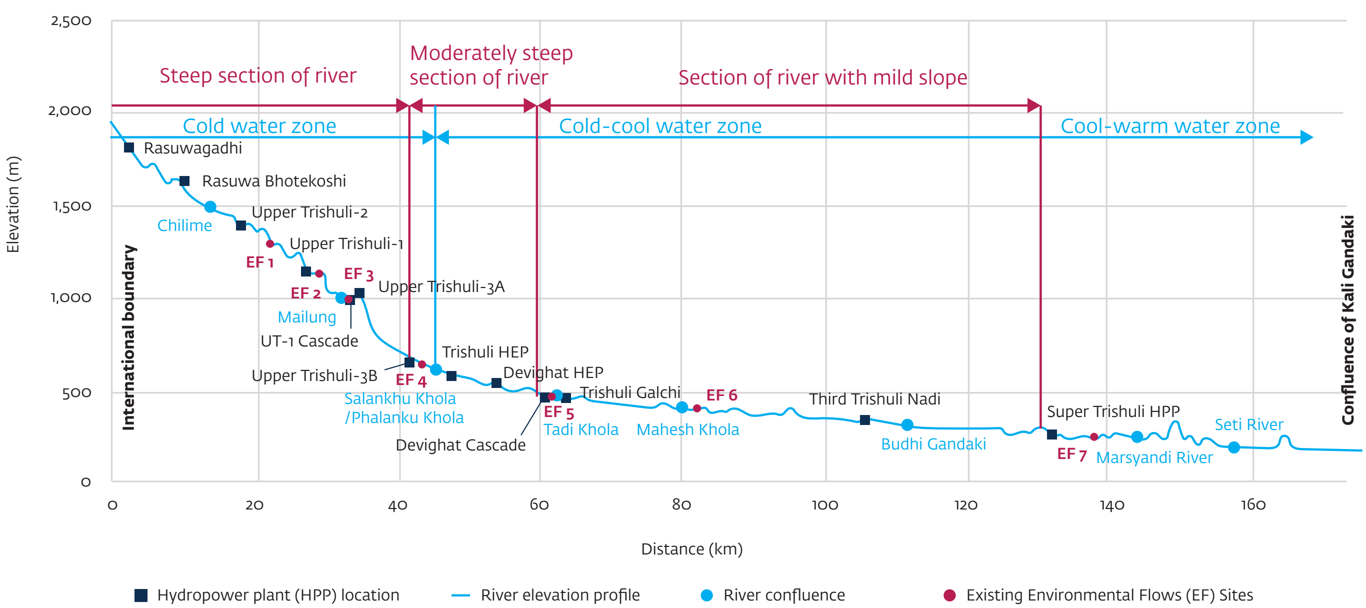
Baseline Conditions

Elevation Profile of the Trishuli River Basin (TRB)

Figure 5.1 illustrates the elevation profile of the Trishuli River and the distribution of elevation and temperature zones. The upper reach of the river from the Chinese border up to the Upper Trishuli-3B hydropower plant (HPP) is steep with an average slope of 3 percent. From Upper Trishuli-3B to just above the Tadi Khola confluence, the river is moderately steep, with an average slope of 1 percent. From there onward, downstream of Super Trishuli, the Trishuli River has a relatively mild slope with an average slope of 0.3 percent.

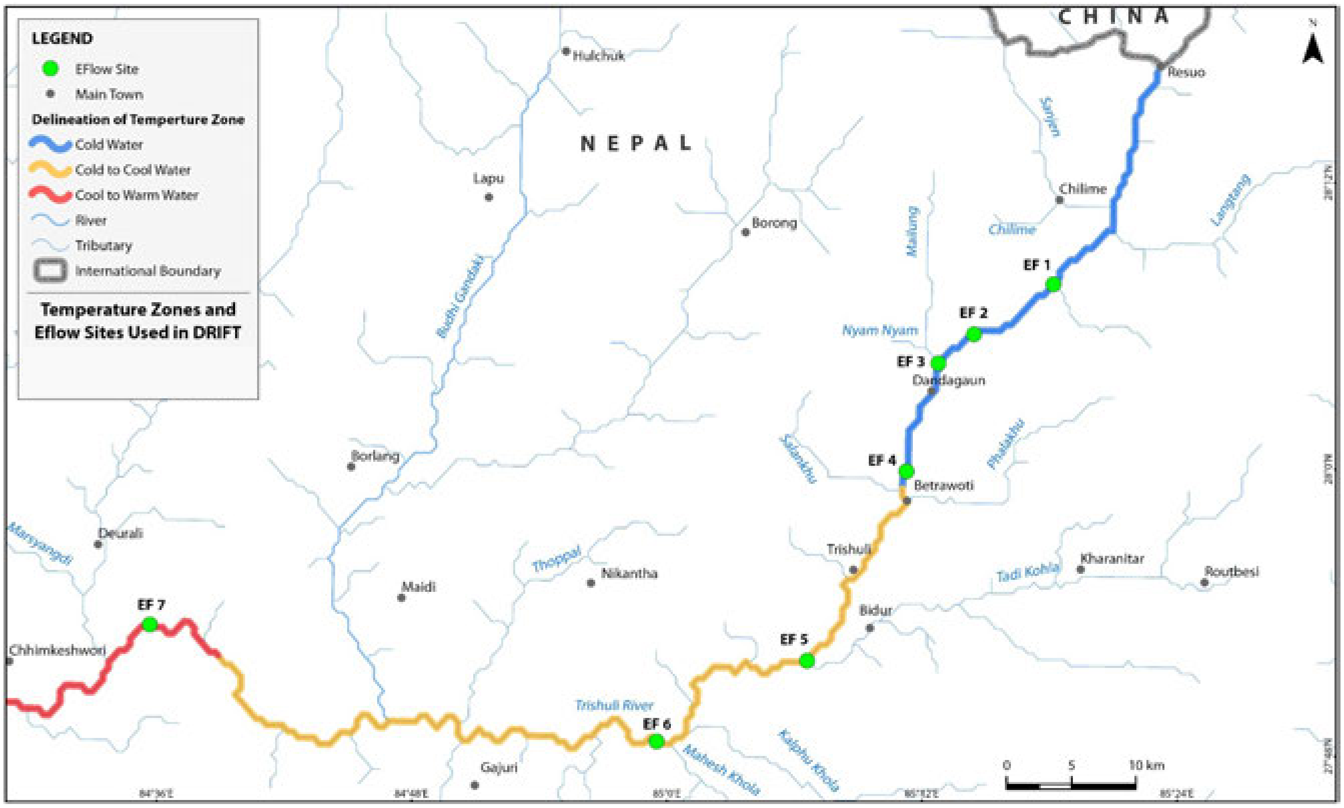
Map 5.1 of the TRB portrays these zones geographically.

Figure 5.1 Elevation Zones of the Trishuli River with Slope and Temperature Zones



Source: *DRIFT Model Report, September 2018, Appendix D.*

Map 5.1 Delineation of Elevation and Temperature Zones



Source: *DRIFT Model Report, September 2018, Appendix D.*

Fish Diversity in the Trishuli River Basin

A total of 60 species of fish have so far been reported for the TRB (Table 5.1). Rajbanshi (2002) provides a summary of fish species from previous studies, while additional field research by Nepal Environmental and Scientific Services (NESS 2012a, 2012b, and 2014a), Sweco (2016), and the Center for Molecular Dynamics-Nepal (CMDN 2018) added species to the list. The International Union for Conservation of Nature Red List of Threatened Species (IUCN 2019) and the Fishbase database (Fishbase 2019) have been used to update the nomenclature.

In March and April 2018, researchers from CMDN applied and tested environmental DNA sampling, also known as eDNA, along the Trishuli River as part of the Cumulative Impact Assessment and Management (CIA) study. The CMDN team collected fish and water samples at six of the seven EFlows sites (EF1 was excluded) (CMDN 2018). See Map 5.2.

eDNA is a new sampling and monitoring method for aquatic diversity and has increasingly appeared to be a promising noninvasive method for improving aquatic biodiversity monitoring. eDNA sampling involves collecting a sample of water, filtering out the detritus, and analyzing the water for DNA, genetic material from aquatic organisms. eDNA is still in experimental stages and thus the analyses conducted are considered preliminary and need to be confirmed and tested with further studies.

The eDNA study tentatively identified 25 species of fish across the six eDNA sampling locations (Table 5.1), although some were only identified to the genus level (for example, *Barilius* sp. and *Schizothorax* sp.). A major challenge is that the reference eDNA database (National Center for Biotechnology Information GenBank) has limited data available on Himalayan fish species, which creates uncertainties in the species identifications from the eDNA study.

Table 5.1 Fish Species Recorded in the Trishuli Basin

English name	Latin name	IUCN Red List status (version 2018-1)	Nepal status (MoFSC 2014)	Endemic to Nepal	Rajbanshi (2002)	NESS (2012a, 2012b, 2014a)	Sweco (2016)	CMDN (2018)
Chaguni	*Chagunius chagunio*	LC	VU	No	✓			
Spotted Snakehead	*Channa punctata*	LC						✓
Angra Labeo	*Labeo angra*	LC		No	✓			
Rohu	*L. rohita*	LC		No				✓
Unknown	*L. dyocheilus*	LC		No	✓			
Kuria Labeo	*L.gonius*	LC		No	✓			
Kalabans	*Bangana dero*	LC		No	✓			
Copper Mahseer	*Neolissocheilus hexagonolepis*	NT	VU	No	✓		✓	✓
Mahseer	*Tor tor*	NT	VU	No	✓			
Golden Mahseer	*Tor putitora*	EN	EN	No	✓			
Rosy Barb	*Puntius conchonius*	LC		No	✓			✓
Dark Mahseer	*Naziritor chelynoides*	VU					✓	
Gangetic Latia	*Crossocheilus latius*	LC		No				
Indian Trout	*Raiamas bola*	LC		No	✓			
Barred Baril	*Barilius barila*	LC		No	✓			
Barna Baril	*Barilius barna*	LC		No	✓			
Indian Trout	*Raiamas bola*	LC		No	✓			
Hamilton's Baril	*Barilius bendelisis*	LC		No	✓			✓
Tileo Baril	*Barilius tileo*	LC		No	✓			
Vagra Baril	*Barilius vagra*	LC		No	✓			

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English name	Latin name	IUCN Red List status (version 2018-1)	Nepal status (MoFSC 2014)	Endemic to Nepal	Rajbanshi (2002)	NESS (2012a, 2012b, 2014a)	Sweco (2016)	CMDN (2018)
Giant Danio	*Danio aequipinnulus*	DD		Yes (upper and middle reaches of Koshi, Gandaki, and Mahakali Rivers)	✓			
Bengal Danio	*Danio devario*	NA		No	✓			
Leopard Danio	*Danio rerio*	LC	VU	No	✓			
Flying Barb	*Esomus danricus*	LC		No	✓			
Blue Laubuca	*Laubuka laubuca*	NA		No	✓			
Gora Chela	*Securicula gora*	LC		No	✓			
Large Razorbelly Minnow	*Salmostoma bacaila*	LC		No	✓			
Annandale Garra	*Garra annandalei*	LC		No	✓		✓	
Gotyla	*Garra gotyla*	LC		No	✓			
Gangetic Latia	*Tariqilabeo latius*	LC		No	✓			
Brown Trout	*Oncorhynchus mykiss*	LC		No (intro-duced)		✓		✓
Common Snow Trout	*Schizothorax richardsonii*	VU	VU	No	✓	✓	✓	
Chirruh Snow Trout	*Schizothorax esocinus*	NA		No	✓			
Dinnawah Snow Trout	*Schizothorax progastus*	LC	VU	No	✓	✓		
Balitora Minnow	*Psilorhynchus balitora*	LC		No	✓			

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English name	Latin name	IUCN Red List status (version 2018-1)	Nepal status (MoFSC 2014)	Endemic to Nepal	Rajbanshi (2002)	NESS (2012a, 2012b, 2014a)	Sweco (2016)	CMDN (2018)
Unknown	*Schistura savona*	LC		No		✓		
Unknown	*Schistura multifasciata*	LC		No		✓	✓	
Stone Loach	*Schistura corica*	LC		No				✓
Stone Cat	*Glyptosternum (Myersglanis) blythi*	LC		No		✓	✓	
Unknown	*Glyptothorax telchitta*	LC		No		✓		
Three Lined Catfish	*Glyptothorax trilineatus*	LC		No		✓		✓
Glypto-thorax Catfish	*Glyptothorax indicus/ garhwali*	LC		No				
Unknown	*Glyptothorax cavia*	LC		No				✓
Mrigal Carp	*Cirrhinus cirrhosus*	LC		No				✓
Common Carp	*Cyprinus carpio*	LC		No				✓
Goldfish	*Carassius auratus*	LC		No (intro-duced)				✓
Stone Carp	*Psilorhyn-choides pseudecheneis*	LC		Yes (however extends into the Ganga River system slightly south of the Indo-Nepal border)	✓			
Stone Loach	*Nemacheilus rupicola*			No		✓		
Gray's Stone Loach	*Balitora brucei*	NT		No	✓			

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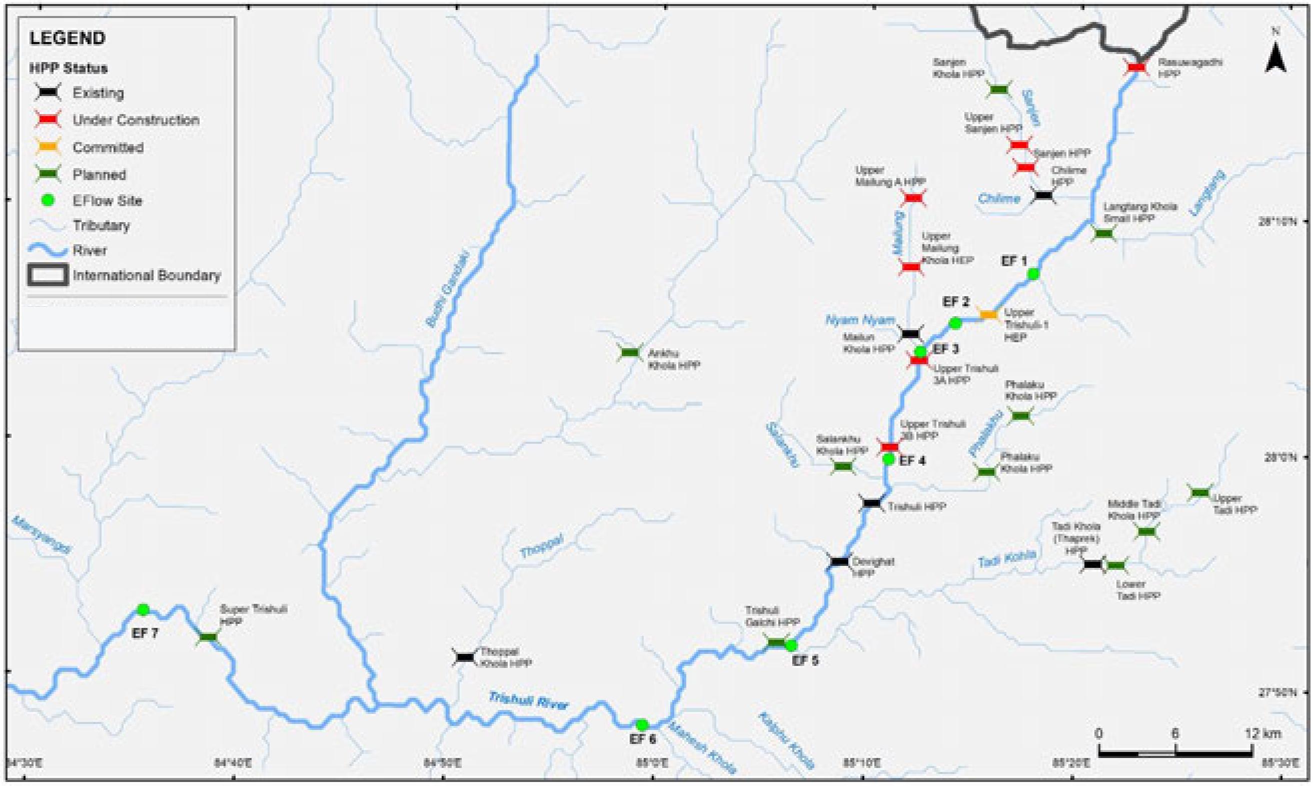
English name	Latin name	IUCN Red List status (version 2018-1)	Nepal status (MoFSC 2014)	Endemic to Nepal	Rajbanshi (2002)	NESS (2012a, 2012b, 2014a)	Sweco (2016)	CMDN (2018)
Mottled Loach	*Acanthocobitis botia*	LC		No	✓			✓
Stone Loach	*Nemacheilus corica*	LC		No	✓			✓
Creek Loach	*Schistura beavani*	LC		No	✓			
Unknown	*Schistura rupecula*	LC						✓
Guntea Loach	*Lepidocephalus guntea*	LC		No	✓			
Almorha Loach	*Botia almorhae*	LC		No	✓			
Yoyo Loach	*Botia lohachata*	LC						✓
Catfish	*Amblyceps mangois*	LC		No	✓			
Sucker Throat Catfish	*Pseudecheneis sulcatus*	LC		No			✓	✓
Torrent Catfish	*Euchiloglanis (Parachilo-glanis) hodgarti*	LC		No		✓		
Dwarf Goonch	*Bagarius*	NT		No	✓			

Note: *IUCN = International Union for Conservation of Nature; MoFSC = Ministry of Forests and Soil Conservation; NESS = Nepal Environmental and Scientific Services; CMDN = Center for Molecular Dynamics-Nepal. IUCN conservation status: EN = endangered, VU = vulnerable; LC = least concern; DD = data deficient, NA = not assessed.*

Map 5.2 EFlows Sites and Hydropower Projects



Source: *DRIFT Model Report, September 2018, Appendix D.*

Aquatic Habitat for Fish Species along the Mainstem

This baseline establishes the key sites for migration, foraging, and spawning across the mainstem of the river and the tributaries. Due to their higher water temperature, tributaries are considered more conducive for spawning for several species.

Cold Zone (Upstream)

Along the Trishuli River, fish are found right up to the Tibet Autonomous Region border. Due to minimal hydropower development in the Tibet Autonomous Region, lower population density, relatively pristine habitat, and altitudes conducive for fish, the Kyirong Tsangpo (name of Trishuli River in the Tibet Autonomous Region) may contain contiguous habitat for coldwater fish species. The EIA for the Rasuwagadhi HPP located three kilometers downstream of the border with the Tibet Autonomous Region (NESS 2012a) reports three species of fish within the project's area of influence; *Glyptothorax telchitta, Glyptothorax trilineatus* (Three-Lined Catfish), and *Psilorhynchus* pseudecheneis (Stone Carp). Given the altitudinal range of the Common Snow Trout (*Schizothorax richardsonii*), 300 meters to 2,810 meters (IUCN 2019, vers.2018-1), this species is also likely found along the river in the Tibet Autonomous Region.

At the Rasuwagadhi site, except for the fecal coliform and turbidity, physical and chemical parameters of the Trishuli River are well within the parameters of the Nepal Drinking Water Quality Standards (NDWQS) (NESS 2012a).

At the UT-1 Site, the water quality was found to be quite good with all parameters well within the NDWQS values (NESS 2012b).

Cold to Cool Zone (Midstream)

The river gets flatter and emerges from the gorge upstream of Betrawati. The riverbed is covered by large boulders, gravels, pebbles of quartzite, gneiss, and phyllite mixed with silty and sandy matrix.

Due to significant urbanization along the banks and sand and gravel mining, water quality deteriorates substantially in this zone. Turbidity, iron, and coliforms and in some locations manganese (Ratmate and Uttar Gaya), exceed the NDWQS (NESS pers. comm.)

This zone is the northern limit for migratory species such as *Tor* (Mahseer), *Tor putitora* (Golden Mahseer), and *Neolissocheilus hexagonolepis* (Copper Mahseer). It is likely that among these species the Copper Mahseer is the most abundant.

Cool to Warm Zone (Downstream)

The Trishuli River flows within a gorge with a width varying between 100 to 300 meters at the valley bottom. The gorge is flanked by the flat alluvial terraces of the Trishuli River, standing at heights varying from 20 to 50 meters on either bank. The riverbed of wide valleys is covered by large boulders, gravels, pebbles of quartzite, gneiss, and phyllite mixed with silty and sandy matrix.

The water quality of the Trishuli River varies significantly in the dry and wet season. In the dry season, as there is little runoff-related erosion in the catchment, the water is relatively free from suspended solids and looks clean, whereas in the monsoon, the runoff-related erosion in the catchment makes it highly turbid, charged with high concentration of suspended solids. Apart from this, the discharge of untreated sewage and disposal of the solid waste from the townships and village located along the Trishuli River also contribute to the river water pollution (NESS 2012b).

This zone of the river has several cold water species including a higher density of Golden Mahseer and Copper Mahseer than the upstream sections of the river. *Bagarius bagarius* (Dwarf Goonch) is not found in the upstream sections of the river.

Aquatic Habitat for Fish in the Tributaries

Cool Zone

Sanjen Khola: The EIA (NESS 2014a) for the planned Sanjen HPP (78 MW) reports that there are no fish in the Sanjen Khola due to temperatures being too cold (180C in October 2013) to support fish fauna.

Chilime Khola: Sweco (2016) sampled Chilime Khola approximately five kilometers upstream of Syafrubesi Bazar and close to where the Khola is dammed upstream and the residual water flow is low. In March there was still sufficient water to provide habitats for fish. The river is a clear water river. The temperature in the Khola on March 3, 2016, at 11.30 am was 16°C. The temperature in Trishuli River was 11°C. Eleven Common Snow Trout in spawning condition were sampled by electro-fishing. In the area above a small waterfall, a single mature male was caught. No fry were observed in this area.

Langtang Khola: This tributary flows into the Trishuli River in the upper reaches. Langtang Khola is a cold snow-fed tributary. No fish were detected in April 2015, when sampled by Sweco (2016). The river temperature at 2 pm on the March 3, 2016 was 11°C, and according to earlier measurements done by NESS (NESS 2012a), the temperature normally is closer to 7–8°C in the morning.

Trishuli Khola: The Trishuli Khola is the first tributary where fish upstream of UT-1/UT-3A/UT-3B, can enter. The Sweco team (Sweco 2016) recorded water temperature on March 4, 2016, at 8.30 am as 9°C. This is a clear river with low exposure to sunlight in the lower parts of the river ravine. The tributary was not sampled, due to steep slopes and landslides caused by earthquakes.

Mailung khola: Mailung Khola is one of few tributaries in the middle Trishuli where fish can enter from the Trishuli River and may have a function in its fish population dynamics. Mailung Khola flows into the Trishuli River just upstream of the UT-3A HPP and downstream of the planned tailrace for UT-1 HPP. The water temperature on at 1 pm on March 4, 2016, was 16°C and the river was clear. Electrofishing by Sweco (2016) resulted in a total catch of 50 fish comprising fry, fingerlings, and mature fish, which is a high density when compared to the Trishuli River. Common Snow Trout was the dominant species while *Glyptosternum blythi* (Stone Cat) and *Psilorhynchoides pseudecheneis* (Stone Carp) were caught in the rapids. Even though the tributary is dammed upstream, Common Snow Trout are found above the dam (H. Kaasa and IFC, pers. comm.)

Cold to Cool Zone

Trishuli River Upstream of Andehri Khola: Sweco (2016) sampled a site upstream of Andehri Khola and downstream of UT-3B HPP. Electrofishing activity was carried out March 2, 2016, at 3 pm. The catch was five Common Snow Trout and one *Neolissocheilus hexagonolepis* (Copper Mahseer), but no fry or fingerlings. The temperature in the river, in this shallow area, was 14°C and the water was light milky green. When searching close to the shore a small tributary was observed, coming from a flat area along the river. Water temperature in this tributary was 20°C. Under a stone in this tributary with water only a few cm deep, 36 Common Snow Trout were seen. Of these, two were fingerlings. Searching a little further upstream, a high abundance of fish was found in a small creek. Further up the creek more fingerlings and fry were detected. The fish density was extremely high. The following additional species were also observed here; *Garra annandalei* (Annadale Gara), *Schistura multififaciatus, Barilius bandelisis* (Hamilton's Baril), and *Glyptosternum blythi* (Stone Cat).

Andehri Khola: Andehri khola is a small tributary with clear water and a high density of fish. The water temperature on February 29, 2106, at 1.30 pm was 20°C (Sweco 2016). Electrofishing was performed in the tributary, while cast net and driftnet were performed in the Trishuli River. The catch in Andehri khola was 412 fish with Common Snow Trout as the dominant species. *Garra sp*. and *Schistura multififaciatus* were also present.

Phalanku Khola and Salankhu Khola: The sampling of fish was carried out on March 4. 2016. The river had clear water and a temperature of 19.5°C at 11 am (Sweco 2016). The electrofishing catch was 56 fish. This is not high density compared to other smaller tributaries. However, it had a very high percentage of fry and fingerlings. Dominant species were *Neolissocheilus hexgonolepis* (Copper Mahseer), *Glyptothorax pectinopterus* (River Cat), *Aspidoparia sps* (Common Snow Trout), *Glyptosternum blythi* (Stone Cat), *Garra annandalei* (Annandale Garra), and *Schistura multififaciatus*. This sampling locality is upstream of the existing Trisuli HPP. Local fishermen said that an extremely big flood last year caused a decrease in the fish population. The fish diversity of the Salankhu Khola is likely to be similar to that of Phalanku Khola.

Tadi Khola: The Tadi Khola aquatic habitat extends upstream of the existing Tadi Khola HPP. This section of the river is likely to be highly fragmented by at least three planned HPPs: Lower Tadi, Middle Tadi, and Upper Tadi. It has yet to be confirmed whether any of the HPPs are planning fish passes, although the IEE of the Middle Tadi HPP does not indicate so. There is little information on the fish fauna of the Tadi Khola, although the Middle Tadi HPP IEE reports the following species upstream of its proposed powerhouse: *Channa gachua* (Dwarf Snakehead), *Garra gotyla* (Gotyla), and Common Snow Trout. It thereby appears that the population of Common Snow Trout is likely to be fragmented once these three dams are constructed.

In addition to a few minor tributaries, the Mahesh Khola, the Kalphu Khola, and the Thoppal Khola also enter the Trishuli River in this zone. There is little information on their baseline status.

Cool to Warm Zone

Tributaries downstream of the Super Trishuli HPP: The spatial boundary of the CIA does not include this area.

Methodology

In this study, the Downstream Response to Instream Flow Transformations (DRIFT) model was used to study impacts of hydropower development on river biodiversity and ecosystems. Details of the application of DRIFT for assessing cumulative impacts are provided in Appendix D. The salient features are as follows:

- DRIFT was used to predict impacts of hydropower project scenarios on the ecological integrity and fish abundance of habitats at selected sites along the Trishuli River mainstem.

- Lessons learned from evaluating EFlows in other projects within the basin and elsewhere in the Himalayan Region, were incorporated.

The following input parameters were used to set up the DRIFT model:

- Seven EFlows sites were established in the main river.

- Daily time series hydrological data were gathered for the seven EFlows sites.

- Assumptions were made on connectivity for upstream and downstream fish migration and connectivity for sediment flow

- Four indicator fish species were evaluated: Snow Trout *(Schizothorax richardsonii*), Golden Mahseer (*Tor putitora*), Buduna (*Garra annandalei*), and Indian Catfish (*Glyptothorax indicus*), which are dependent on the following indicators; geomorphology, algae, and macro-invertebrates.

The justifications for using these indicator species in DRIFT are provided in Appendix D.

Key Stressors

The following stressors have been identified as impacting water quality and thereby aquatic biodiversity.

Sand and Gravel Mining

"Riverbed Sand and Gravel Mining" in Chapter 3 provides information for the Trishuli River. Sand and gravel mining is likely to result in greater turbidity thereby deteriorating habitat for aquatic diversity. Released minerals from mined deposits are also likely to degrade water quality. Due to the proximity of machinery to the river, there is likely to be a higher discharge of leaked compounds, such as hydrocarbons, into the river. Furthermore, any camps associated with mining may result in disposal of untreated solid and liquid waste into the river. Finally, the mining itself directly causes major alteration of the natural riverbed habitat.

Access Roads

All communities interviewed indicated that building of access roads for village infrastructure has led to loss of soil stability, exacerbating landslides. This is compounded by deforestation caused by upstream communities. Landslides and dumping of spoil from road construction result in solids pollution of the Trishuli River, with a likely significant increase in total dissolved solid levels and degrading aquatic habitats. The summary (ERM 2018) suggests that the cold and cold-cool zones experience high to medium risks of landslides and, given substantial road development in this area, are likely to have significant degradation of aquatic habitats by landslides and dumping of spoil from road construction.

Climate Change

As indicated in the "Climate Change" subsection of Chapter 3, the 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 is observed. This reflects that the glacier contribution at the dry season is becoming less over time while the rain contribution during the wet season is not uniform. Greater unreliability of dry season flows poses potentially serious risks to water supplies in the lean season, as hydropower projects are highly dependent on predictable runoff (Bajracharya, Acharya, and Ale 2011; Bajracharya and Shresthra 2011).

A reduction of lean season water to the head-works could result in a reduction in the environmental release into diversion reaches. This could further exacerbate degradation of habitats and impediments to migration caused by present low flows. However, it needs to be established whether this is conceivable within the 50 year temporal boundary.

Significant Impacts

Cumulative impacts have been assessed from the DRIFT model. The setup of the model in terms of the input parameters used the scenarios modelled, and the results are provided in Appendix D. This section summarizes the results in Appendix D with appropriate interpretation. For explanations of terms such as *ecosystem integrity* and *fish integrity*, please refer to Appendix D.

Integrity ratings arose from initial calculations of predicted abundance of fish, which were then compared with baseline values. Changes were assigned as positive or negative depending on whether an increase in abundance was a move toward or away from the baseline. For ease of interpreting the results, Table 5.2 provides the ecological category for the abundance changes and its implications for habitat alteration.

Fish Integrity

Table 5.3 provides fish integrity scores for the seven EFlows sites for each of the four project-development scenarios. A key assumption made for all scenarios is that the barrier effect of the weir as a percentage of reduction in fish migration is 100 percent for fish migrating upstream and 90 percent for fish migrating downstream. These cumulative impacts were predicted for HPPs without including mitigation such as fish passes in place.

The fish integrity scores for four scenarios are derived from the DRIFT model. However, these results have been extrapolated for scenario 3 of complete development using the following rationales:

EFlows Site 1: The population of fish will decline further with additional hydropower projects under the full development scenario (scenario 3). There will be marginal impacts on the fish population in Langtang Khola, as this tributary is snowmelt fed and does not offer much breeding and spawning ground for fish. The impacts on the fish in Chilime Khola (which already has two under-construction and one existing project) will be also marginal. However, additional HPPs in Trishuli Khola will impact fish. Overall ecosystem integrity is estimated to drop from C/D to D at EFlows site 1 with the additional HPPs in the "planned—survey license given" scenario.

EFlows Site 2: The population of fish will drop further at EFlows site 2 due to the addition of UT-1 HPP to

Table 5.2 Ecological Integrity Ratings

Ecological category	Corresponding DRIFT overall integrity score	Description of the habitat condition
A	>-0.25	Unmodified. Still in a natural condition.
B	>-0.75	Slightly modified. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged.
C	>-1.5	Moderately modified. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged.
D	>-2.5	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	>-3.5	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	<-3.5	Critically/Extremely modified. The system has been critically modified with an almost complete loss of natural habitat and biota. In the worst instances, basic ecosystem functions have been completely altered, and the changes are irreversible.

Source: *Kleynhans 1996.*

Table 5.3 Fish Integrity at Seven EFlows Sites

EFlows site/ reach	Existing (Scenario 1)	Under-construction (Scenario 2a)	Under-construction and committed (Scenario 2b)	Full development (Scenario 3)
EFlows Site 1	C	D	F	F
EFlows Site 2	C	D	F	F
EFlows Site 3	D	F	F	F
EFlows Site 4	D	D	D	E
EFlows Site 5	D	D	D	E
EFlows Site 6	C/D	C/D	C/D	E
EFlows Site 7	B	B	B	C

the cascade of UT 3A and B in the full development scenario. However, ecosystem integrity, which will already be very low at this site with 24 existing, committed, and planned HPP projects, will remain at E.

EFlows Site 3: The population of fish will significantly drop at EFlows site 3, with the addition of three HPPs: UT-1, Middle Mailung, and Upper Mailung B. Fish breeding in the main Trishuli River and Mailung Khola will occur at this site in the summer, however, the fish will be trapped between the dams and will not be able to access favorable feeding and breeding areas. The breeding in Mailung Khola will further decline with the additional HPPs in this tributary. The contribution of Mailung Khola to population of fish in the main Trishuli River at EFlows site 3 will therefore decline further. The overall ecosystem integrity will drop from D to E category.

EFlows Site 4: The population of fish will drop further at EFlows site 4 due to addition of Middle Trishuli Ganga Nadi HPP in the "planned—survey license given" scenario. The overall ecosystem integrity will drop from C/D to D at this site.

EFlows Sites 5, 6, and 7: Additional projects will not have a significant incremental impact on the population of fish, and overall ecosystem integrity will remain the same at these sites.

Additional projects in Tadi Khola tributary will have impacts on the fish populations in the upper reaches of Tadi Khola. However, these projects will not have a significant incremental impact on the population of the Common Snow Trout or Golden Mahseer in the main Trishuli River, as existing projects on Tadi Khola have already isolated the upstream breeding and feeding areas of these fish from the Trishuli River.

These rationales are also relevant for explaining changes to overall ecosystem integrity as described in "Overall Ecosystem Integrity" of Chapter 5. Appendix D provides a species specific account on the cumulative impacts that can be predicted for each of the four indicator species.

Map 5.3 spatially illustrates the deterioration of fish integrity across the existing projects and full development scenario.

Overall Ecosystem Integrity

Table 5.4 provides the baseline ecosystem status (BES) at the seven EFlows sites along the Trishuli River.

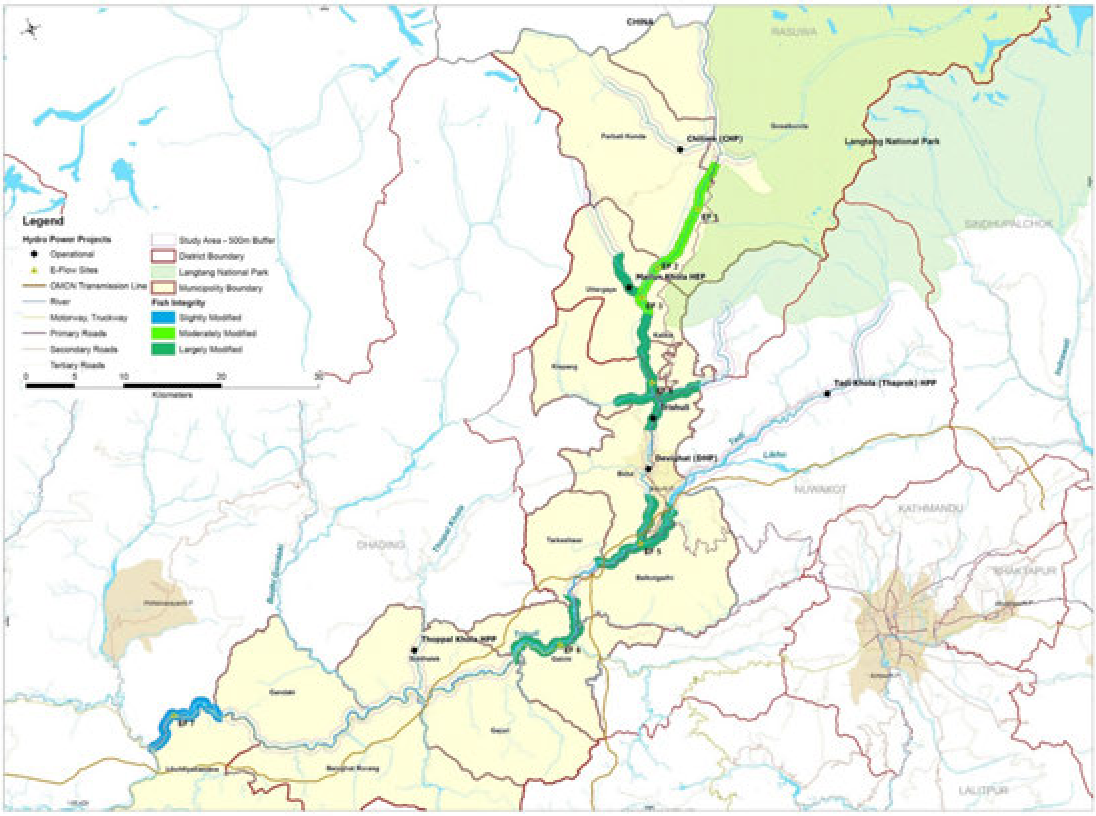
With the six scenarios in place the BES is expected to change as indicated in Table 5.5 at each of the EFlows sites.

As mentioned above, ecosystem integrity is significantly influenced by fish integrity.

There are no large storage dams in the study area with peaking (peaking power generation refers to an operating regime where high flows are passed through turbines for limited durations to maximize

Map 5.3 Fish Integrity: Existing and Full Development

a. Existing scenario (Scenario 1)



b. Full-development scenario (Scenario 3)

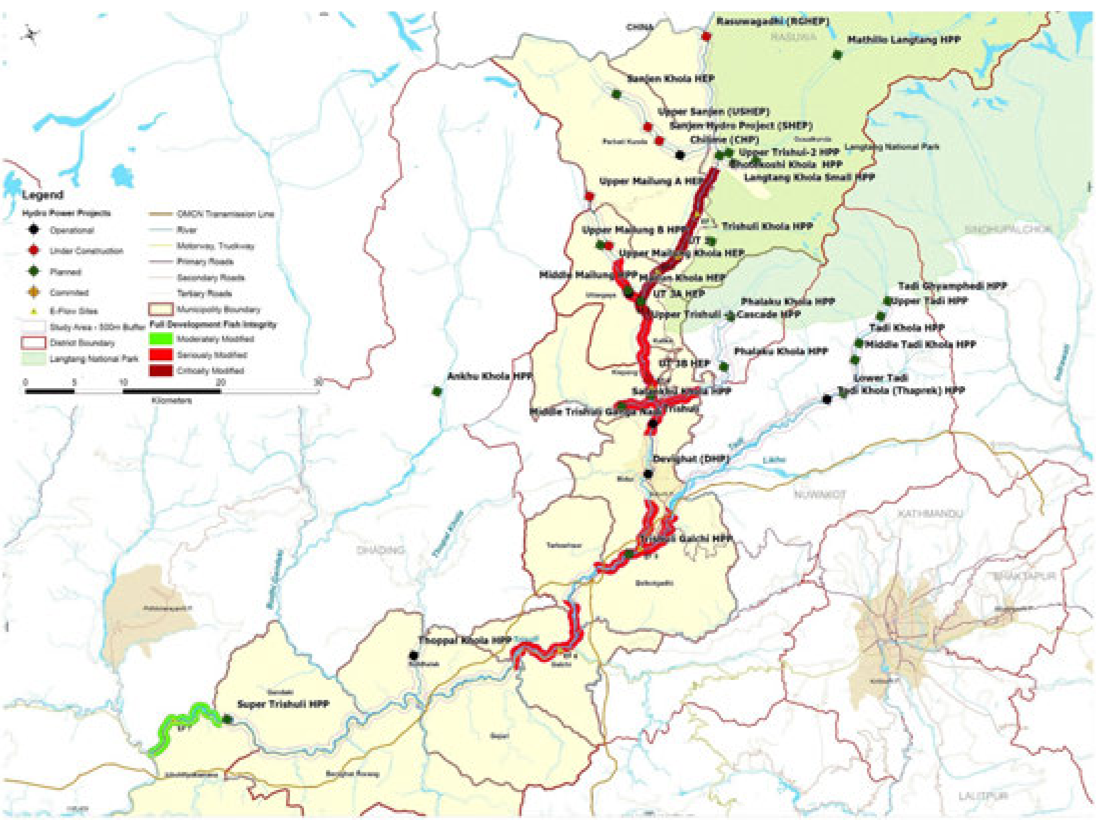


Table 5.4 Baseline Ecological Status of the Trishuli River

Discipline	EFlows Site 1	EFlows Site 2	EFlows Site 3	EFlows Site 4	EFlows Site 5	EFlows Site 6	EFlows Site 7
Geomorphology	A/B	A/B	A/B	A/B	B/C	C	B
Algae	B	B	B	B	B/C	D	B
Macro-invertebrates	B	B	B	B	C	D	B
Fish	B/C	B/C	B/C	B/C	B/C	C	B
Overall ecosystem integrity	B	B	B	B	B/C	C	B

Table 5.5 Overall Ecosystem Integrity

EFlows site/ reach	Existing (Scenario 1)	Under-construction (Scenario 2a)	Under-construction and committed (Scenario 2b)	Full development (Scenario 3)
EFlows Site 1	B	B/C	C/D	D
EFlows Site 2	B	B/C	E	E
EFlows Site 3	C	C/D	D	E
EFlows Site 4	C	C	C	D
EFlows Site 5	C	C	C	D
EFlows Site 6	C/D	C/D	C/D	D
EFlows Site 7	B	B	B	C

power production during periods when demand and consequent power prices are high) planned for any of the projects. The hydrology will remain unaffected in a true run-of-the-river (RoR) operation mode. With very limited storage capacities, the capacity of the dams to store sediment will also be very limited, although the impacts of sediment will be initially high, when the reservoirs are filling up with sediment. Loss of river habitat due to inundation will also be low as the reservoir areas are small. A few of the projects have extended low flow sections, such as UT-1 and the rest are mostly small HPPs.

With such a large number of projects with relatively small capacities and limited storage operating in true RoR mode, the barrier effect will be the predominant impact of hydropower development in both the main river and tributaries. Upstream fish migrations and access to feeding and breeding areas will be impeded. Common Snow Trout will be mostly impacted in the upstream sections, while Golden Mahseer will be affected in the lower reaches.

Furthermore, due to the addition of these projects, the abundances of algae and macro-invertebrates, which are already low at sites 4, 5, and 6 as a result of heavy sand and gravel mining, remain unaltered due to the addition of dewatered section and altered flow. Similarly, the geomorphological condition at sites 4, 5, and 6 are likely to remain unaltered with new projects added to the basin.

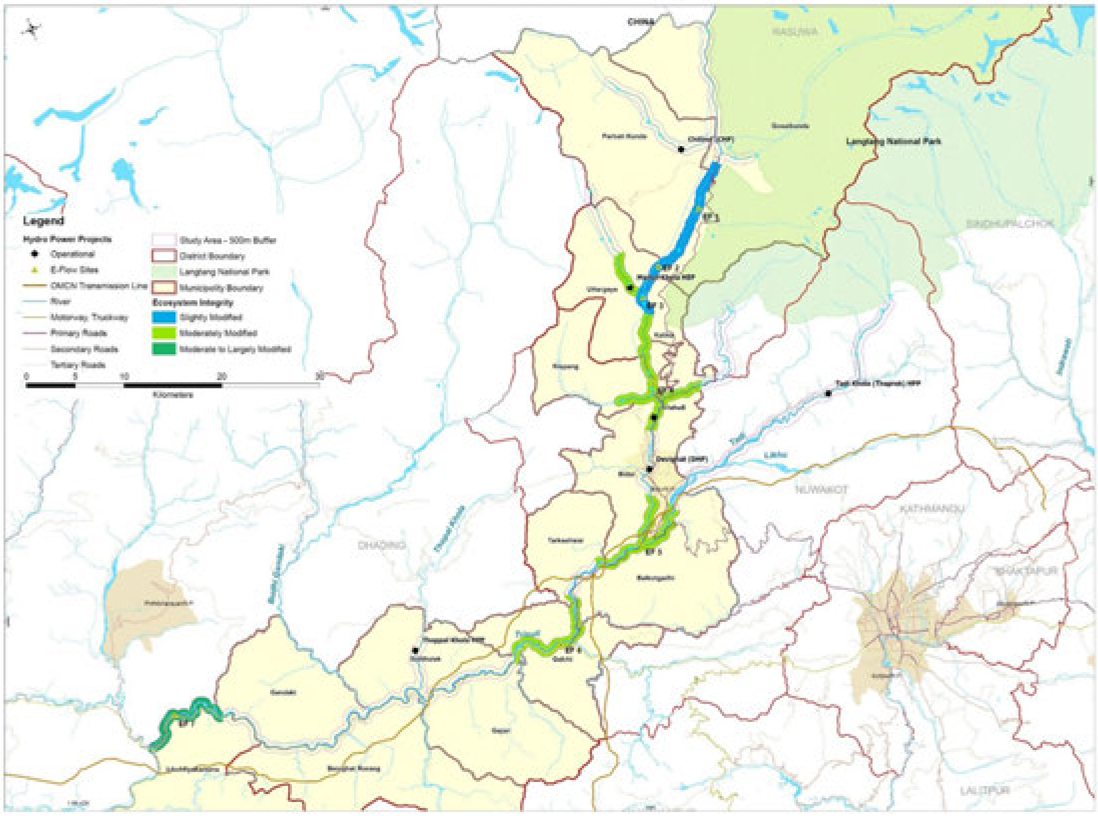
Map 5.4 spatially indicates the deterioration of ecosystem integrity across the existing projects and full development scenario.

Fragmentation of Aquatic Habitat due to Hydropower Development

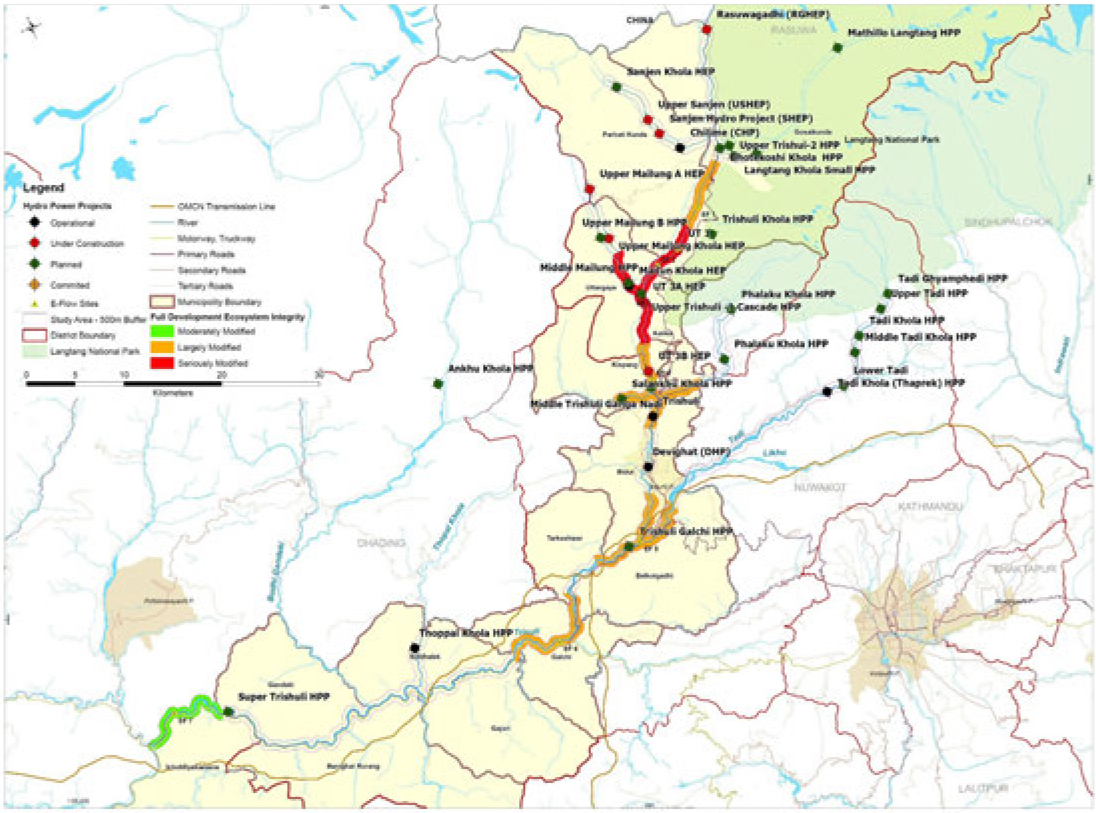
The aquatic habitat of the Trishuli River has already been partially fragmented by two existing hydropower projects: Upper Trishuli 3A HPP and the Trishuli HPP. These dams form a barrier to upstream migration

Map 5.4 Ecosystem Integrity: Existing and Full Development

a. Existing scenario (Scenario 1)



b. Full-development scenario (Scenario 3)



of migratory fish species, including the Common Snow Trout. Fish, including adults, fry, and larvae, are able to move downstream over the low weirs of these dams. Trishuli HPP has only a half weir and an underwater sluice gate that permits fish to pass downstream. Thus, habitats for the main migratory fish species in the Trishuli River, the Golden Mahseer and Common Snow Trout, are currently fragmented into three sections.

It is anticipated that with additional dams under the scenarios discussed, both the mainstem of the river and tributaries where dams are planned will be further fragmented, which will result in small isolated populations of these two fish species. In the midstream section and along the tributaries, this effect will be more relevant for Common Snow Trout. Golden Mahseer access to upstream areas of the Tadi Khola and Salankhu and Phalanku Kholas, has already been obstructed, due to dams such as the existing Trishuli Dam.

Proposed Mitigation

The following mitigation actions, listed according to impact, are possible means of reducing the cumulative impacts of development on the aquatic environment in the TRB.

Barrier Effects and Low Flows along the Trishuli Mainstem

Passage

- Research is needed to understand fish behavior for upstream and downstream migrations across dams, to support design of fish passages that are effective.

- In many cases, fish passes are poorly designed and do not work. An apparent example is the fish pass designed for UT-3A project, which was damaged by the earthquake and is presently being repaired.

- Fish passages are often not considered due to the height of the dam. In general, fish passages can be designed fairly easily for dams of 10 meters or less. However, dams of 30 meters or more can also include some type of fish passage such as a fish ladder or fish lift.

- Successful fish passages in Nepal should be used as examples for fish passage design and operation for the fish species of interest in the TRB, namely Snow Trout and Mahseer. In the TRB, UT-1 has planned a fish pass for Snow Trout utilizing international expertise. Two other projects, Super Trishuli and Rasuwagadhi HPP, have also planned fish passes. Khimti Khola HPP has a fish passage designed to simulate natural conditions (H. Kaasa, pers. comm.).

- There are examples of functioning fish passages in other countries that can also be used to guide the design, operation, and monitoring of a successful fish passage in the TRB (Schmutz and Mielach 2015). There are also many examples of failed fish passages that should be reviewed to avoid similar problems in Nepal.

- Information is needed to understand where fish passages are planned for projects in the basin and where fish passages are needed to maintain continuity right through the cascade.

- Guidelines should be prepared for the design of fish passes specifically suited for indigenous species (IFC 2018b). Continuous research, guided by monitoring, is needed to improve the design of passages and to identify technologies that are suited for particular conditions.

- Development of a robust methodology for monitoring the effectiveness of fish passages (for example, counting the number of fish that pass through the ladder) is needed for all HPPs with a fish passage.

- Capacity building is needed for hydropower project environmental staff as well as for government employees who work with fish passages in order to ensure that they are able to monitor and assess the efficacy of the passages.

Design and Management of EFlows in Low Flows and Bypass Sections

- EFlows should be designed within the framework of sustainable development to balance conservation of aquatic ecosystem with loss in power generation as EFlows are increased.

- Nepal's guidelines for EFlows, which require EFlows to be 10 percent of the minimum average monthly flow, should be reevaluated to include evaluation and management of impacts of flow modifications on biodiversity. IFC guidelines on selection of EFlows methods could be adopted as a model (IFC 2018a).

- Attention should be given to management of EFlows in cascades, where there should be consistency in operating rules for the powerhouses, and operation of power plants should be coordinated to maintain EFlows in the cascade.

- Further research is needed on the habitat requirements of fish and other aquatic species in relation to river flow rate, water depth, and so forth in order to provide the data needed for EFlows assessments and an underlying rationale for the selection of EFlows.

    - Nepal government hydropower regulators should increase monitoring and inspections to ensure that EFlows, as determined by the EFlows assessment, are released. They should consider requiring HPPs to post real-time EFlows data on their website to facilitate monitoring of EFlows.[1]

Management of Peaking

- A basin-level strategy should be developed for collaboratively designing power plants in the basin to avoid peaking designs where possible and to minimize impacts of peaking when not.

- For any hydropower projects considering peaking operation, a robust EFlows assessment should be conducted to evaluate a range of peaking scenarios in order to reach a balance between power generation and environmental protection.

- Peaking operations should consider options for regulating peaking impacts such through a cascade or with a regulating dam downstream.

Management of Sand and Gravel Mining

- Dams should be designed to let the sediments through, minimizing accumulations in reservoirs.

- Sustainable sediment mining plans should be formulated on a scientific basis, to balance the economic benefits of mining with the impact of mining on aquatic ecosystems and to achieve a win-win for the economy and the environment.

- Due to the high mining pressures in the lower reaches of the TRB, sediment-mining plans need to be developed and enforced for each hydropower project and for the basin. While a policy will be needed at the federal government level, enforcement will have to be organized at provincial and local level.

Management of Unregulated Fishing

- Sustainable harvesting practices need to be introduced. There are some examples where commercial harvesting of fish is regulated by the government, such as on the Mahakali River.

- Regulation of fishing by communities should be explored.

- Subsistence fishing should be allowed where sustainable, but fishing methods should be controlled, and use of destructive practices such as electrocution and fishing with nets of fine mesh sizes should be prohibited.

- The use of chemicals to catch fish should be strongly prohibited. By using chemicals or biocides, both macroinvertebrates and fish and their fry are killed. Use of these chemicals not only poisons the fish but is also dangerous for people who eat the fish.

1 See the example for AD Hydro Power Limited projects (Allain and Duhangan) in India at http://hppcblive.com/live/allain.

Research on Aquatic Ecology

- There is a need for the development of a robust methodology per international standards to establish baselines for aquatic biodiversity during an ESIA process, as well as methodologies for long-term monitoring of aquatic habitats and biodiversity. A good understanding of river ecosystems is required for managing impacts of hydropower on fish populations. This will include aquatic biodiversity, composition, and distribution of fish species and the importance of connectivity between the main river and tributaries (see IFC 2018a, 2018b).

- Some hydropower projects have already been constructed. The impacts of these on fish populations need to be studied to understand how future projects will impact the aquatic ecosystems and fish populations.

- Novel and new survey and monitoring methodologies should be explored and tested (e.g. eDNA) and training provided to hydropower project environmental staff and government staff.

  - Capacity building is needed for hydropower projects environmental staff as well as for government employees who work with fish passages in order to ensure that they are able to monitor and assess the efficacy of the passages.

- Government should review and update regulations for aquatic habitat protection as needed.

Native Fish Hatcheries

- Fish hatcheries, or other captive propagation of fish, are often the preferred mitigation option for hydropower projects.

- Many Himalayan fish species, including the Snow Trout and Mahseer, are able to be bred in captivity in Nepal.

- However, many studies of fish in other countries have shown that hatchery-bred fish are not as healthy or robust as wild fish and that they do not serve to increase the wild populations when released (Brown and Day 2002). Few, if any, studies have been conducted on hatchery fish released in the Himalayas in order to determine success rates.

  - Hatcheries should not be considered a primary mitigation option, as they are unlikely to help in maintaining wild fish populations. More research is needed to understand the conditions under which hatcheries can help. Until then, other mitigation options that are proven to work should be investigated, and research should be carried out on how to supplement fish populations in the wild through hatcheries.

Barrier Effects and Low Flows along Tributaries

Tributaries entering the main stem of the Trishuli River, in addition to offering habitat for fish, are also important spawning areas. As discussed for the river's mainstem, prior to designing mitigation, there needs to be a thorough understanding of patterns of aquatic biodiversity, the composition and distribution of fish species, and the location of spawning sites (see IFC 2018a and 2018b). Tributaries are a key to the viability of fish populations in the TRB, as they serve as spawning areas, nursing areas, and recruitment areas. Tributaries are highly threatened in the TRB as a series of dams, such as those planned along the Mailung, Phalanku, Salankhu, and Tadi Kholas, not only impede migration upstream, but isolate existing populations into small fragmented populations with limited chances of survival.

Furthermore, low flows caused by diversion for power generation, for the same tributaries mentioned above, alter habitat and impede migrations by lowering depth over and above low natural depths already existing in tributaries. It may added here that several tributaries such the Sanjen and Langtang Kholas are snow fed and do not provide spawning habitats, so those that do are quite vital for fish survival in the basin.

The following recommendations are relevant for all tributaries providing habitat and spawning opportunities for fish:

- River stretches between hydropower projects should be thoroughly assessed for fish diversity and their

abundance. This will not only provide information on how important the assessed tributaries are for the viability of fish populations in the basin, but will provide valuable information for designing mitigation, such as spawning species, seasons for spawning, and priority spawning sites.

- Every hydropower project should do an adequate EFlows assessment (as per IFC 2018a) and not simply follow the 10 percent of the minimum monthly flow recommendation. A major parameter to be assessed is the flow to be released in the migratory season for fish to reach spawning sites.

- Fish passage should be included on dams along tributaries, particularly because these dams are often less than 10 meters high and therefore well suited for fish ladders. Where possible, dams (maintaining riverbed level and dam slope) should have weirs mimicking the natural flow of the rivers so that fish can pass.

- Government monitoring should be increased to ensure that EFlows, as determined by the EFlows assessment, are released.

- Hydropower project planning by government agencies such as the Department of Electricity Development should consider the number of projects on each tributary. Mailung Khola is a snow-fed river directly impacted by climate change. Other tributaries do not enter the Mailung Khola. As a result, Mailung Khola may become oversaturated with projects, and other tributaries should be identified that should not have any future hydropower plans and can be used as an offset.

- For rivers like the Trishuli, where the fish population in the main river seems to be directly dependent on the fish production in the tributaries, it would be important to investigate the relative importance of each tributary for the total fish population. Such tributaries may act as refuges for the fish population.

- Hatcheries for indigenous fish species should be only a back-up/low priority alternative.

- Adequate baseline surveys and monitoring following robust methodologies and research on fish migration patterns and biology are needed for tributaries in the basin.