Environmental and Social Impact Assessment (Draft): Appendices (Part 2)

Project Number: 49086-001
March 2018

NEP: Upper Trishuli 1 Hydropower Project

Prepared by Environmental Resources Management (ERM)

Appendix C
Flora within the Environmental Area of Influence

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FLORA WITHIN THE ENVIRONMENTAL AREA OF INFLUENCE

Table 1: Tree Species

SN	Scientific name	Nepali name
1	*Aesandra butyracea*	Chiuri
2	*Albizia chinensis*	Kalo siris
3	*Alnus nepalensis*	Utis
4	*Bauhinia purpurea*	Tankee
5	*Boehmeria rugulosa*	Dar
6	*Bombax ceiba*	Simal
7	*Callicarpa arborea*	Maas Gedaa
8	*Cassia fistula*	Raajbriksha
9	*Castanopsis indica*	Dhalne katus
10	*Cinnamomum spp.*	Sinkaulee
11	*Engelhardia spicata*	Mauwa
12	*Ficus semicordata*	Khanayo
13	*Lagerstroemia* spp.	Asare
14	*Lyonia ovalifolia*	Angeri
15	*Machilus duthiei*	Kaulo
16	*Mallotus* spp.	Sindure
17	*Mangifera indica*	Aanp
18	*Melia azadirach*	Bakainu
19	*Myrica esculenta*	Kafal
20	*Phyllanthus emblica*	Amala
21	*Pinus roxburghii*	Rani sallo
22	*Populus ciliata*	Bhote pipal
23	*Rhododendron arboreum*	Lali gurans
24	*Rhus wallichii*	Bhalayo
25	*Salix spp.*	
26	*Schima wallichii*	Chilaune
27	*Shorea robusta*	Sal
28	*Symplocos pyrifolia*	Seti kath
29	*Syzygium cumini*	Jamun
30	*Terminalia alata*	Saaj
31	*Toona ciliata*	Tunee
32	*Unidentified 1*	Maletro
33	*Unidentified 2 (Araliaceaea)*	
34	*Unidentified 5*	Dipath (Tamang)
35	*Unidentified Rosaceae*	

Table 2: Shrub Species

SN	Scientific name	Nepali name
1	*Achyranthes aspera*	Datiwan
2	*Agave americana*	Ketuki
3	*Ageratina adenophora*	Banmara
4	*Berberis asiatica*	Chutro
5	*Boehmeria platyphylla*	Kamle
6	*Chromolaena odorata*	Aule banmara
7	*Clerodondron serratum*	
8	*Colebrookia oppositifolia*	Dhusure
9	*Cotoneaster microphyllus*	
10	*Desmodium tiliaefolium*	Rato bakre ghans
11	*Euphorbia royleana*	Siundee
12	*Gaultheria fragrantissima*	Dhasingare
13	*Hypericum cordifolium*	Areli
14	*Indigofera constricta*	
15	*Indigofera dosua*	Phusre ghans
16	*Inula cappa*	Gaitihare
17	*Lonicera quinquelocularis*	Bangjhi
18	*Maesa chisia*	Bilauni
19	*Mimosa* spp.	
20	*Murraya paniculata*	
21	*Osbeckia stellata*	Rato chulsi
22	*Osyris wightiana*	Nun Dhicki
23	*Oxyspora paniculata*	
24	*Phyllanthus parvifolius*	Khareto
25	*Prinsepia utilis*	Dhatelo
26	*Rhamnus virgatus*	Kande painyu
27	*Rubia manjith*	Majitho
28	*Rubus ellipticus*	Ainselu
29	*Rubus foliolosus*	Kalo ainselu
30	*Sarcococca coriacea*	Fiti fiya
31	*Senna occidentalis*	Thulo Tapre
32	*Senna tora*	Tapre
33	*Solanum aculeatissimum*	Kantakaari
34	*Viburnum erubescens*	Ganmane
35	*Woodfordia fruticosa*	Dhainyaro
36	*Zanthoxylum acanthopodium*	Boke timmur
37	*Unidentified 4 (Urticaceae)*	

6 Table 6.2-5: Herb Species Report from the Environmental Area of Influence

SN	Scientific name	Nepali name
1	*Ageratum conyzoides*	Gandhe
2	*Amaranthus spinosus*	Lunde kanda
3	*Arisaema concinnum*	Sarpa ko makai
4	*Arisaema tortuosum*	Sarpa ko makai
5	*Artemisia vulgaris*	Titepati
6	*Arthraxon lancifolius*	Chitre bans
7	*Arundinaria* spp.	
8	*Arundinella nepalensis*	Phurke Khar
9	*Begonia picta*	Magar kanche
10	*Bidens pilosa*	Tikhe kuro
11	*Boenninghausenia albiflora*	Daampate
12	*Brachiaria ramosa*	Likhe Banso
13	*Calanthe puberula*	
14	*Carex cruciata*	Lamo hat katuwa
15	*Cheilanthes* spp.	
16	*Chrysopogon gryllus*	Dhaple ghans
17	*Cissampelos pareira*	Batul pate
18	*Clematis spp.*	
19	*Commelina benghalensis*	Kane
20	*Crassocephalum crepidioides*	Anikale jhar
21	*Curcuma angustifolia*	Kalo besar
22	*Cynodon dactylon*	Dubo
23	*Cynoglossum zeylanicum*	Kanike kuro
24	*Cyperus niveus*	Seto mothe
25	*Delphinium altissimum*	Bikhadi ghans
26	*Dicranopteris linearis*	
27	*Dioscorea bulbifera*	Gitthe tarul
28	*Dioscorea deltoidea*	Bhyakur tarul
29	*Drepanostachyum falcatum*	Sano nigalo
30	*Dryoathyrium* spp.	Kalo neuro
31	*Dryopteris chryso*coma	
32	*Eulaliopsis binata*	Babiyo
33	*Fragaria nubicola*	Bhuin ainselu
34	*Galium asperuloides*	
35	*Geranium nepalense*	
36	*Girardinia diversifolia*	Allo sisnu
37	*Hedychium ellipticum*	Rato saro
38	*Impatiens amplexicaulis*	Tiuree
39	*Imperata cylindrica*	Siru
40	*Ipoemea* spp.	
41	*Iris decora*	Padam pushkar
42	*Leucostegia immersa*	
43	*Lindelofia longiflora*	
44	*Malaxis muscifera*	
45	*Mentha* spp.	
46	*Murdannia edulis*	Nigale gava
47	*Nephrolepis cordifolia*	Paniamala
48	*Oleandra wallichii*	
48	*Onychium* spp.	
50	*Osbeckia stellate*	Rato chulsi
51	*Persicaria* spp.	

SN	**Scientific name**	**Nepali name**
52	*Phyllanthus urinaria*	Bhuin amala
53	*Polypodium* spp.	
54	*Polystichum prescottianum*	
55	*Pteris* spp.	
56	*Saccharum spontaneum*	Kans
57	*Satyrium nepalense*	
58	*Selaginella* spp.	
59	*Selinum tenuifolium*	Bhutkesh
60	*Sida* spp.	
61	*Spilanthus acmella*	Marati
62	*Thalictrum foliolosum*	Dampate
63	*Thalictrum punduanum*	Dampate
64	*Thalictrum spp.*	
65	*Thysanolaena maxima*	Amreso
66	*Unidentified 3 (Poaceae)*	
67	*Urena lobate*	Nalu kuro
68	*Urtica dioica*	Sisnu
69	*Xanthium strumarium*	Bhende kuro

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Appendix D
Design Advice on Fish Ladder and Associated Spillway Designs at the UT-1 Hydropower Project

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REPORT

NWEDC

NEPAL WATER & ENERGY DEVELOPMENT COMPANY

Upper Trishuli-1

14685001

Design Advice on Fish Ladder and Associated Spillway Designs at the Upper Trisuli-1 Hydropower Project

JANUARY 2018

Sweco Norway AS

DEPARTMENT OF ENVIRONMENT

HALVARD KAASA

SWECO

REPORT

Report no.: 4	Project no.: 14685001	Date: January 2018
Client: NWEDC		

Design Advice on Fish Ladder and Associated Spillway Designs at the Upper Trisuli-1 Hydropower Project

This report describes the design advice on fish ladder and associated spillway at the UT-1 intake site, and as requested by NWEDC the report give comments to other challenges connected to the UT-1 HP development and to the river connectivity.

NWEDC comments 19th of January 2018	**Report revised 29th of January 2018**
Created by: Halvard Kaasa	**Sign:** Halvard Kaasa
Project responsible / dept.: Sweco Norway AS	**Manager approval:** Karel Grootjans

Content

1 Introduction

The 216 MW upper Trishuli-1 Hydropower Project is located in the Rashuwa District of Nepal. It is a run-of-the-river project, and the developer is the Nepal Water & Energy Development Company Private Limited (NWEDC).

As a part of the process to ensure compliance of the Upper Trishuli-1 Hydropower Project (UT-1HPP) with Nepal national regulations and the IFC's Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Resources, NWEDC are required to build a fish passage across the intake weir.
This report gives comments and recommendations for technical solutions to keep river connectivity when the UT-1 is in operation.

2 Conditions for design

A) Fish species

The overall dominat species in the UT-1 area of Trisuli is Asala (Shizothorax richardsonii). Shizothorax progastus per the EIA with recordings from 2011, and a report from DoFD from 2008/2009, has been detected in the area of UT-1 for 6 and 9 years ago.
In the agreement between NWEDC and Sweco Norge AS it is clearly mentioned that the fish ladder design shall be accommodated for the target species Shizothorax richardsonii and also for the Shizothorax progastus if this species is present in the area.
The last years S. progastus is not registered during field studies connected to the environmental program of UT-1.
Normally S.progastus has its preferred biotopes in lower altitudes (300 -850 m above sea level) and in warmer waters than at UT1. It might therefore be a possible explanation that S.progastus can be observed in the UT-1 area in varying degree depending of ecological conditions as water temperature, flow and population size. Another important measure might be the possibilities of upstream migrating obstacles as the cross-section dam at UT3A just downstream the UT-1 area. This UT3A dam site has been without a fish ladder the last years, but a fish ladder is planned to be built. Information given by NWEDC indicate that there is another HP planed just upstream of UT-1 Called UT-2 HEP that shall be developed with a cross section dam and a fish ladder.

As discussed with NWEDC the design of the fish ladder for UT-1 will be with focus on Shizothorax richardsonii and, as last years of registrations show, not accommodated for S. progastus.

B) Flow through the fish ladder

In this report, the fish ladder flow proposal interplay with the NWEDC minimum release proposal that is 10% of mean monthly flow which mean a little bit less than 4 m^3/s during the spring season (UT-1 Detail Design Report 2017). On that basis, the flow in the fish ladder will approximately be 1 m^3/s and with additional attraction water to the entrance of the fish ladder of 1 m^3/s. This mean that the total flow connected to the fish ladder entrance is approximately 50% of the minimum flow. The rest of the e-flow that will be released from the head pond, shall flow into the pool at the entrance of the fish ladder. From an ecological point of view the fish ladder do not need to be operated during the period when there is now upstream fish migration in the UT-1 area.

C) Available space

The space along the riverside downstream the dam is per information from NWEDC restricted and there is not available area to prepare a nature liker fish way. Due to the height of the dam and the available space there is need to design a compact fish ladder.

3 The fish ladder principles

The fish ladder shall mainly serve the upstream migration of the target species Snow Trout (Shizothorax richardsonii). The total height of the fish ladder will be approximately 30 m. The exact height will be decided when the design of the fish ladder entrance pool is settled. To meet the requirements for migration of Snow Trout the total number of pools will be close to 100.

3.1 The entrance pool outside the fish ladder

In principle, the entrance pool just outside the fish ladder shall be attractive for Snow Trout. Substantial flow and spurt of water are qualities needed to attract this species. Approximately 50% of the proposed minimum flow will enter the pool from the fish ladder. Rest of the e-flow passing from the head pond shall also enter the pool outside the fish ladder. See figure 1.

The conditions in the pool outside the fish ladder entrance is crucial for the functionality of the fish ladder.

A. The conditions in the river up to the outlet from the fish ladder must be adapted to the behaviour of the migrating fish species during the whole upstream fish migrating season.
B. The fish ladder entrance pool shall be situated close to the upper part of the fish migrating section.
C. Water velocity in the pool where water passing outside of the entrance of pool no 1, shall be no more than 0,3m - 0,6 m/s during the upstream migrating period.
D. The pool shall be equipped with some hiding-places for fish
E. The depth outside the entrance of the fish ladder shall be at least 2m.
F. If needed this pool shall be sheltered from high flows and high current velocities originated from the spillway and from the radial gates. This to prevent damage on the fish ladder entrance and to avoid bad conditions for fish.

3.2 Fish ladder pool no 1

The pool no 1 is 5m x 4,3 m and the inside height is 2,5 m (see Figure no 1 and the enclosed drawings in attachment 1).
The outlet from the chamber has two vertical slots with the ability to let trough 1,5 m^3/s with highest water velocity of 1m/s and that the step between water level in the outside pool and in the chamber no 1 is between 0,20 – 0,25 m dependent of the flow variations. The width of the openings is 0,6 m (Figure 2).

At the bottom of the chamber there shall be constructed hiding places for Shizothoracx richardsonii, where they can hide during daytime. These hiding places should be possible to cleane for sediments if needed.

Attraction water shall be added at the top of the concrete roof that is covering chamber 1 and 2. (see Figure 4). Water shall fall from the 5 m wide front of the distributor bay and hit the water surface just outside the vertical slot entrance. Attraction water shall also enter Pool no 1 trough pipes in the concrete roof. The total amount of attraction water added shall be approximately the same flow as in the fish ladder. See figure 1 and attached drawing of the fish ladder entrance (Attachment 1).

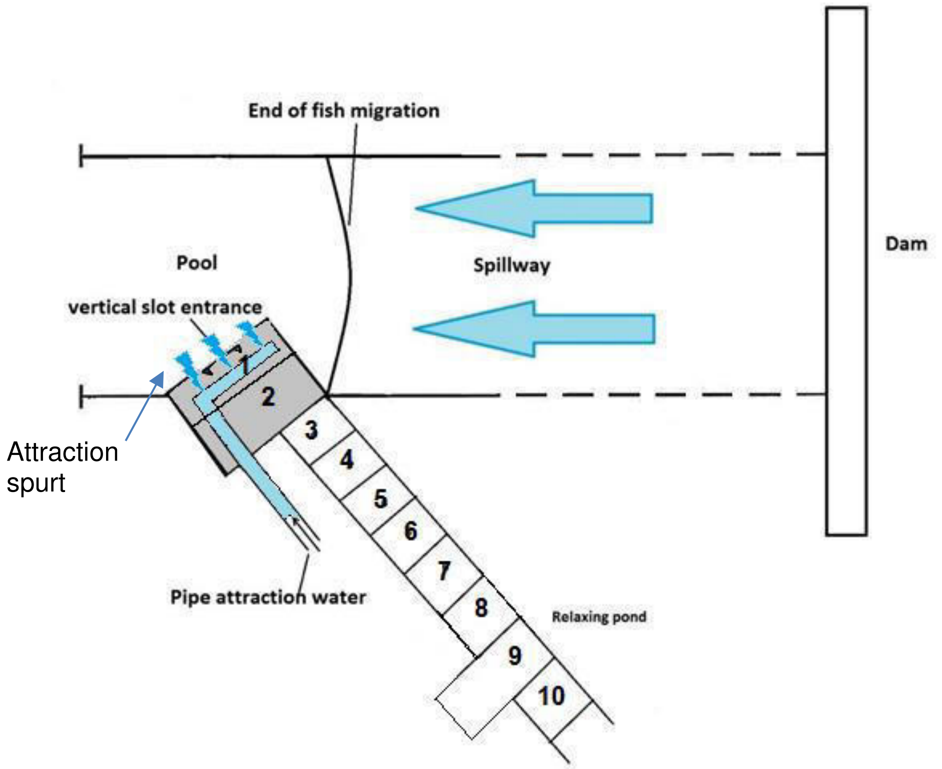

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Fig. 1 The principal of the fish ladder entrance.

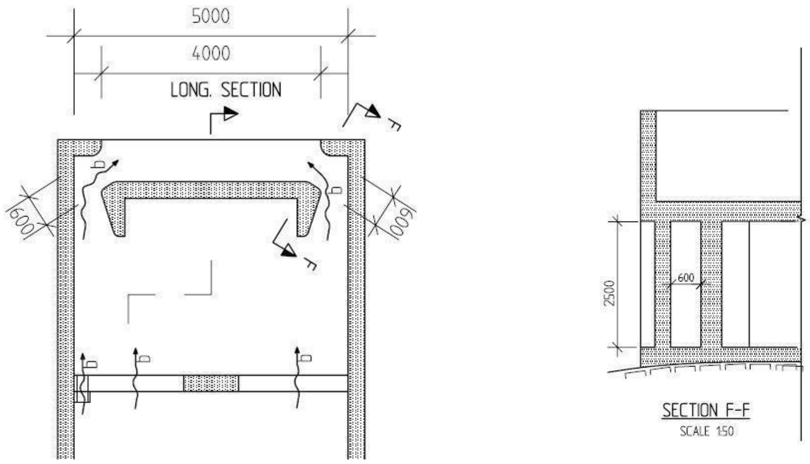


Figure 2. Transekt including vertical slots

3.3 Fish ladder pool no 2

The pool no 2 is 5m x 3 m and the inside height is 2,5 m. Here are two notches in the front wall to slow down the water velocity, see figure 3. The water velocity shall be below 1,5m/s and the step between chamber 1 and chamber 2 shall be between 0,23 – 0,27 m dependent of the flow variations.
There is an orifice at the right side and close to the bottom of 0,2m x 0,2 m that is possible for fish to enter and also serve as a drainage of the upstream chamber.

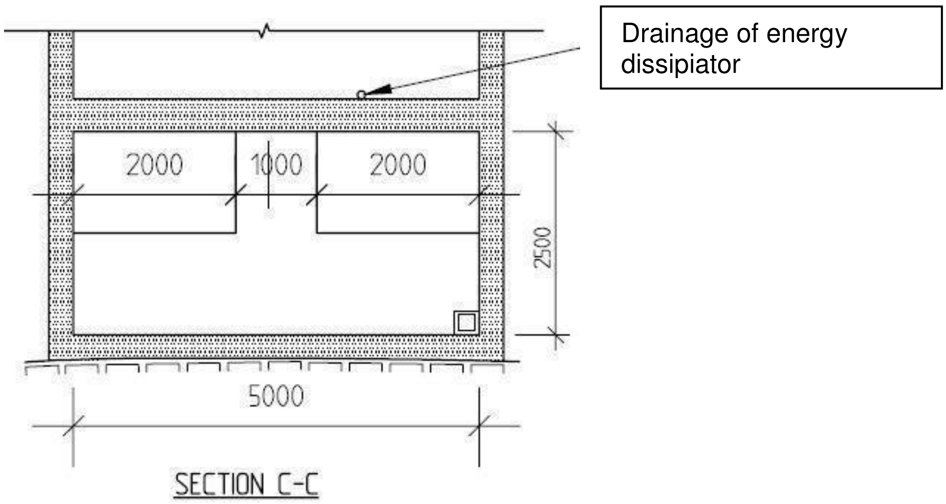


Fig. 3 Outlet from pool no 2 have 2 overflow notches.

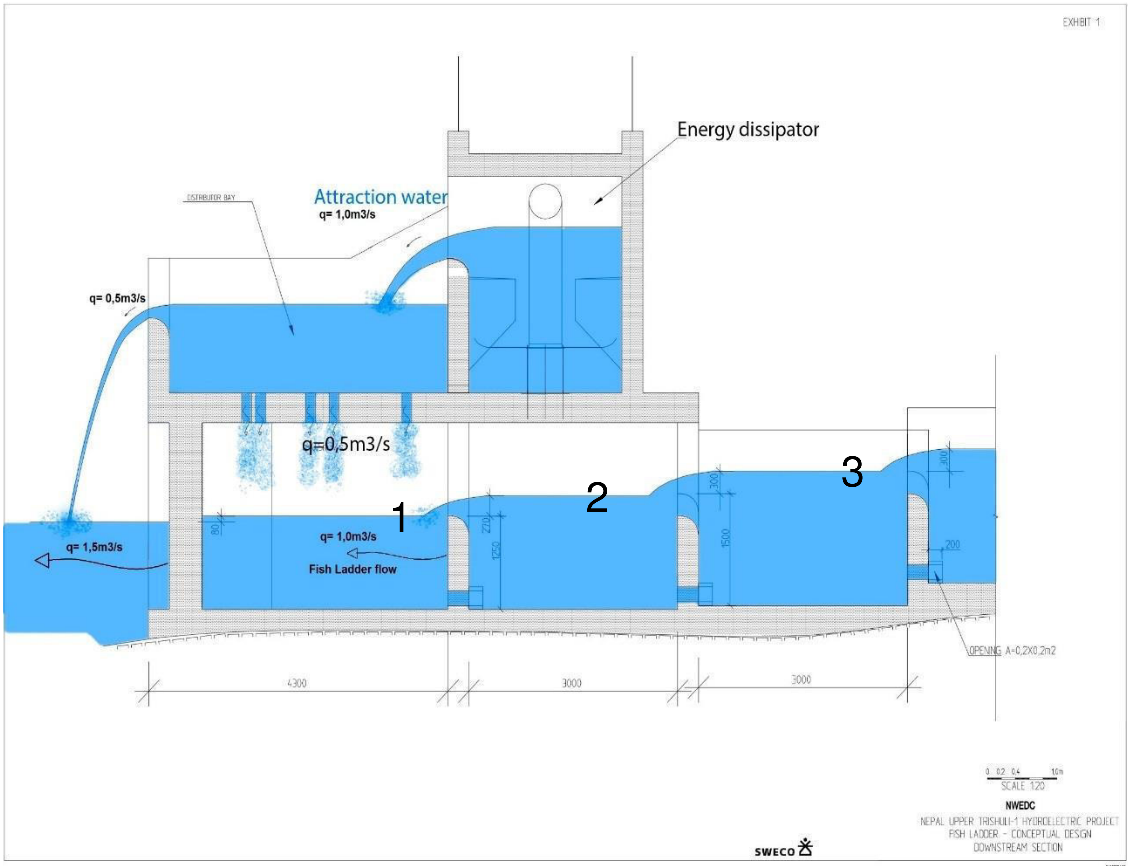


Figure 4. The 3 first fish ladder pools, the attraction water energy dissipiator as well as visualization of the distribution of the attraction water in front of pool no 1 and also direct to pool no 1.

3.4 Fish ladder pool no 3 to 8

The pool no 3 to no 8 is 4 m x 3 m with inside height of 2,5 m. Here is one notch in the front wall as shown in Figue 5. The design gives good hydraulic conditions for Snow Trout (Shizothorax richardsonii) with flow up to 1m^3/s. In the front wall in each pool it is an orifice close to the bottom of 0,2m x 0,2 m that is possible for fish to enter, and that also serve as a drainage of the upstream chamber. Maximum velocity trough the overflow notch shall be 2m/s. The step between the overflow notch to the water level downstream shall be approximately 0,3m (see figure 3), and the notch alters between right and left position se Figure 6.

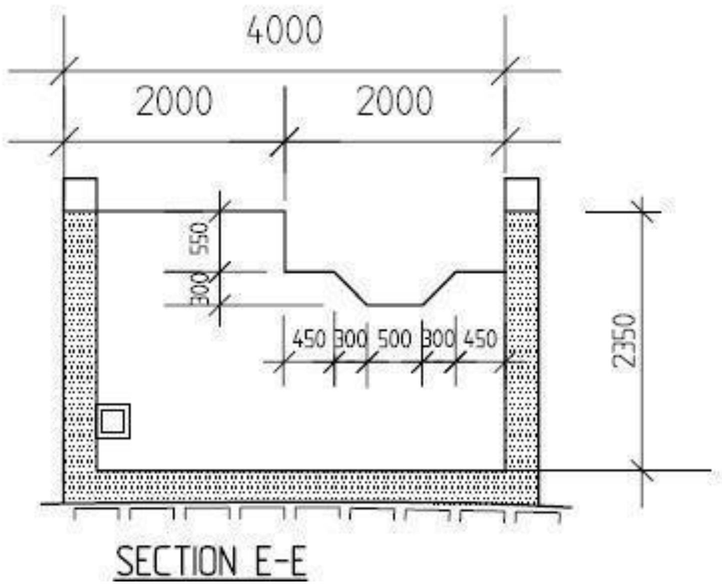


Figure 5 The outlet from fish ladder pool no 3 to no 8 has a notch designed to give good hydraulic conditions with flow up to 1m³/s. This notch is alternating right and left as moving upstream.

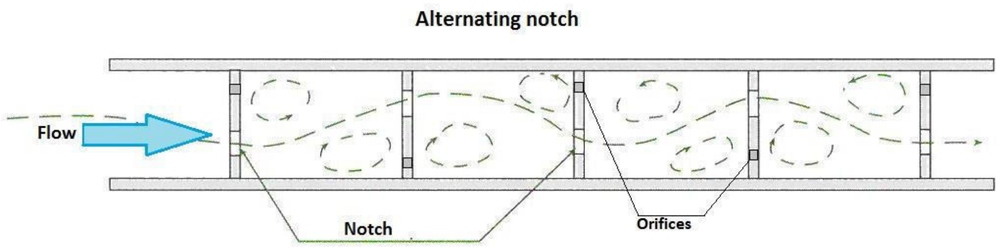


Figure 6 Principal of altering notches in a fish ladder

3.5 Fish ladder pool no 9

The fish ladder pool no 9 is a resting pool of 5 x 4m and inside height 2,5 m see Figure 1. The inlet and outlet notches of this chamber is as in chamber nr 3 to 8. See figure 5 and 7. At the bottom of the chamber there shall be constructed hiding places for Shizothoracx richardsonii. This hiding places must be constructed so as it is possible to clean the pool for sediments. This type of resting pools shall be repeated upstream in the fish ladder with 6 normal pools in-between.

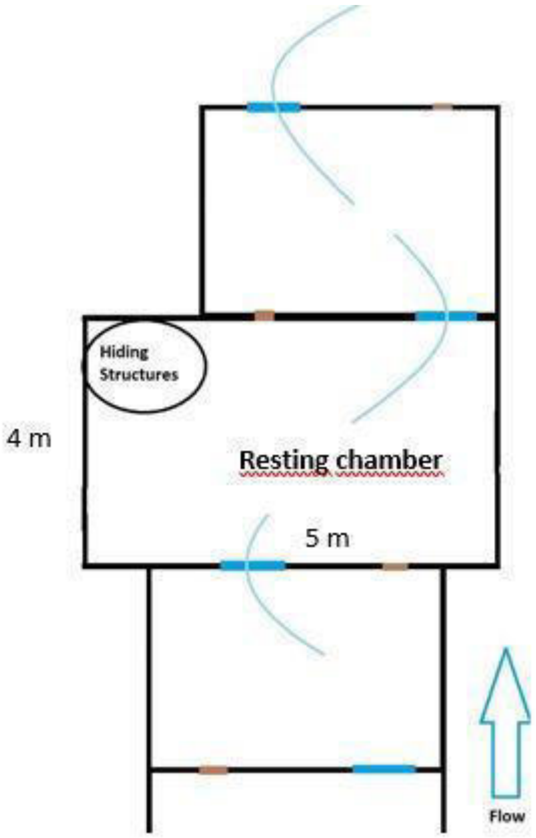


Figure 7 Resting camber or resting pool is bigger than the normal fish ladder pools and is equipped with hiding structures at the bottom level in the calm part of the pool.

3.6 Fish ladder pool no 10 and to the top of the ladder

After pool no 9 every seventh pool shall be a resting pool, the other pools shall be of same size and principle as chamber 3 with alternating notches. The pools might be built in other combinations than straight after each other. For instance, different compact solutions, see examples Fig. 8. This way of preparing the design must be decided by NWEDC as a function of the available space at Haku site.

At the top of the fish ladder where the ladder enters the weir there shall be a technical solution that may adjust the flow into the ladder according to the water level in the intake pond. The top fish ladder pool shall be 4m x 3m as pool no 3, and the flow from the inlet weir head pond approximately 1 m^3/s with relative slow velocities with maximum 0,7m/s from the weir head pond to the top fish ladder pool. This make it easy for migrating fish to enter the weir head pond.
The inlet from the head pond to the fish ladder must be equipped with a gate to control and finetune the flow in the fish ladder. It must also be possible to turn of the fish ladder flow and if necessary to include an automatic adjustment of the fish ladder flow as a function of the

water level in the weir head pond. As described by NWEDC the normal elevation in the intake pond is EL 1255.
The exit from the fish ladder at the top of the weir shall be localized as far away from the HP intake site as possible and in an area where the water velocities upstream the weir and outside the topmost chamber in the intake pond shall be not more than 0,3m/s. These conditions must be considered by design of the weir.
The design of these technical facilities shall be done by NWEDC.

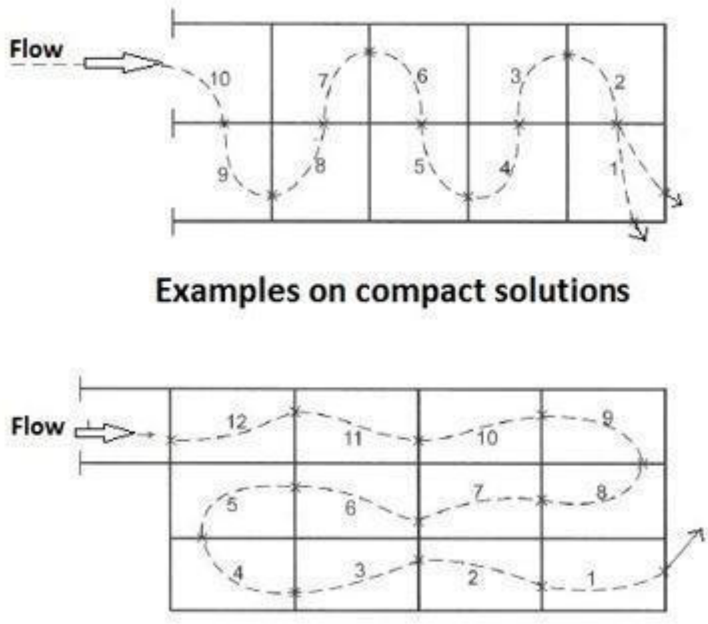


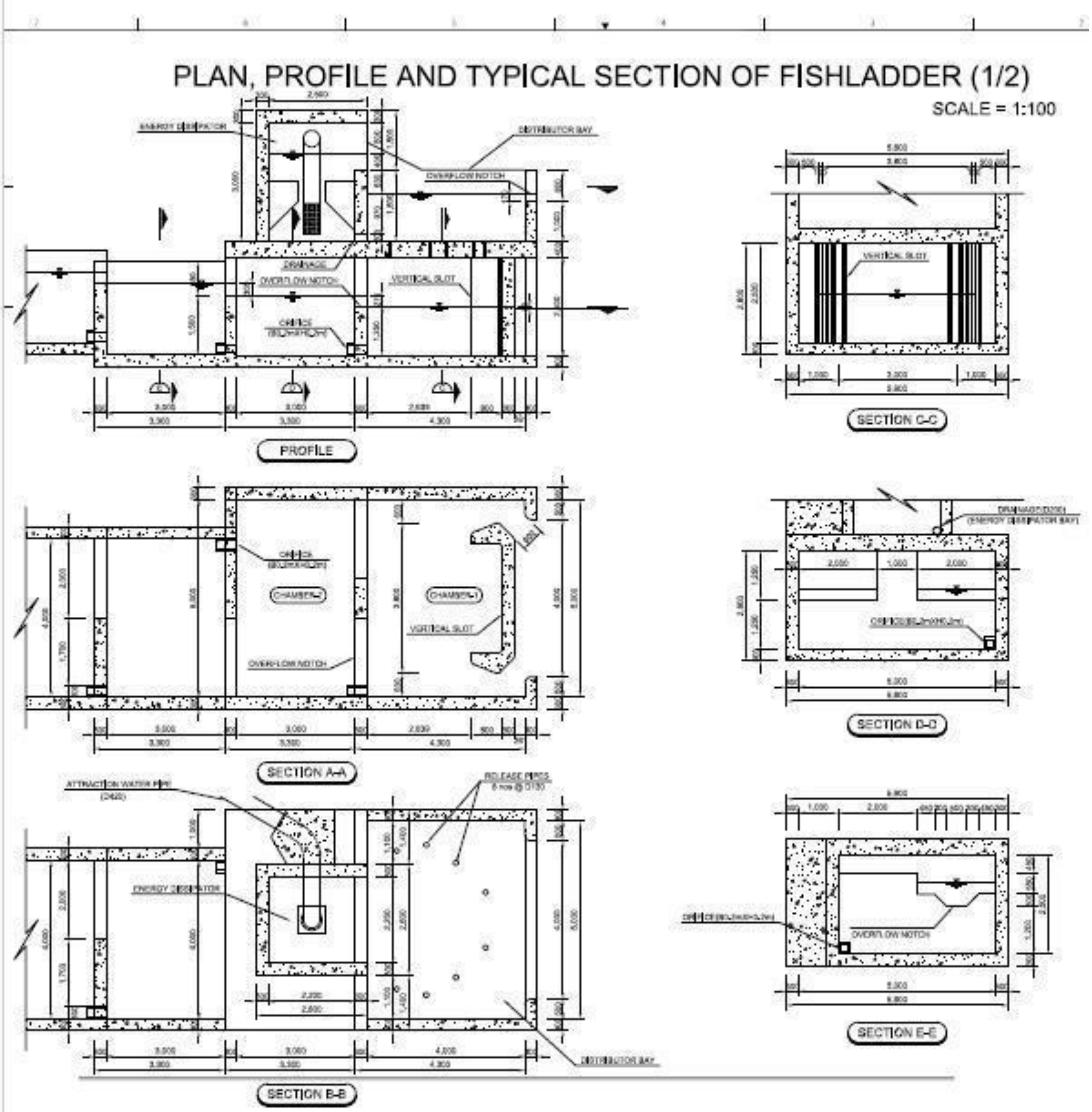
Figure 8. Examples of compact design of fish ladders.

4 Evaluation of the fish ladder design prepared by NWEDC's Design engineers (DKJV).

Based on the principles of the fish ladder design prepared by Sweco, se chapter 3 and attachment 1 in this report, NWEDC's design engineers in DKJV has prepared the fish ladder drawings shown in figure 9. Review of this drawings by SWECO gave 2 comments:

1) The overflow weirs are shown with square edges. They should preferably be given a rounded upstream face as shown on the Sweco-drawing (Conceptual design, attachment 1). A square edge will raise the water level more than the estimated level,
2) The outlet of the attraction water pipe (in the energy dissipator box) should be fixed with bars of stainless steel (as shown on the Sweco-drawing). Design engineer shall incorporate these two points.

Looking at fish ladder design in figure 9 (1/2 and 2/2), prepared by DKJV, it seemed that principles of fish ladder design suggested is incorporated and that design as such is appropriate for fish migration.


PLAN, PROFILE AND TYPICAL SECTION OF FISHLADDER (1/2)
SCALE = 1:100
PROFILE
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E

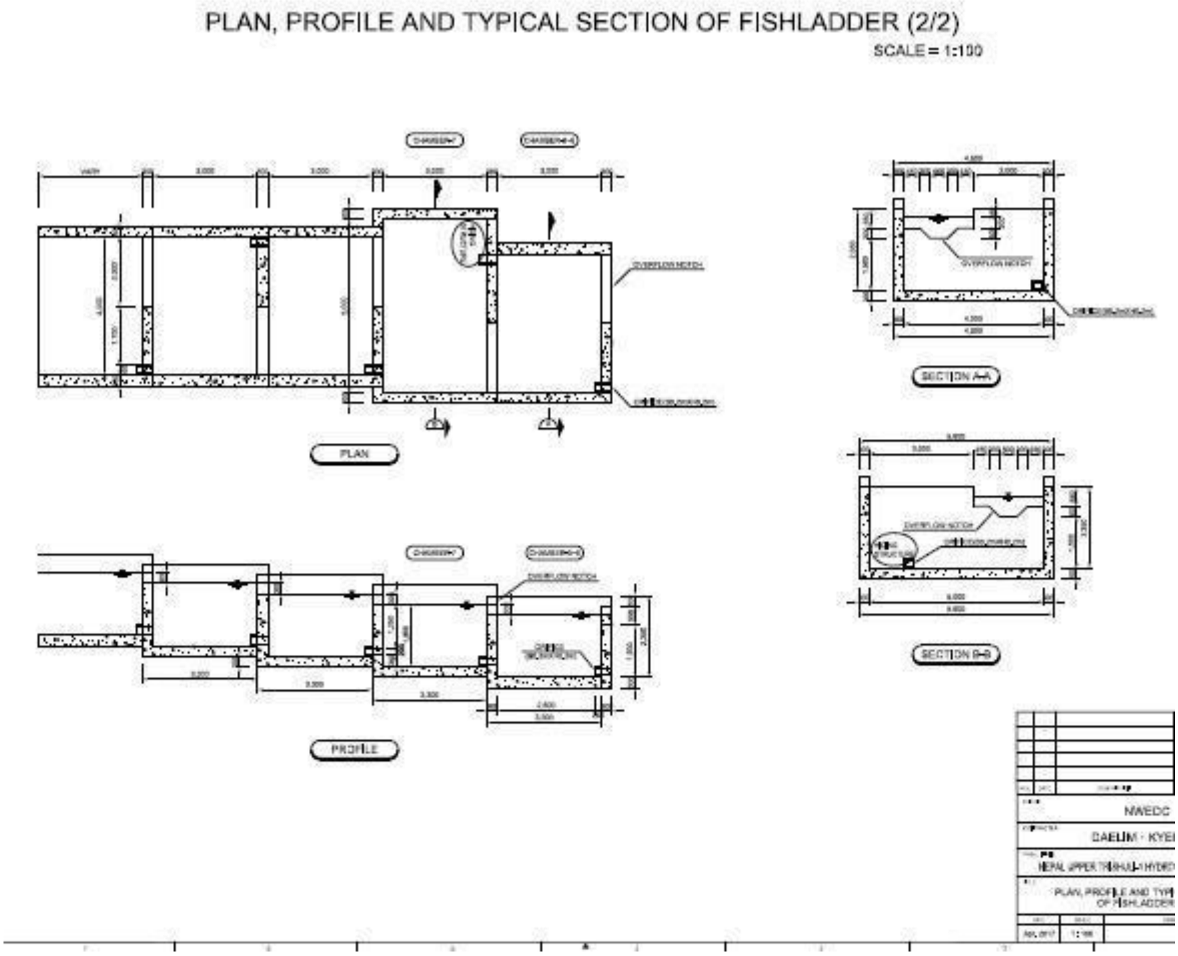


Figure 9, consisting of two parts 1/2 and 2/2. Plan Profile and Typical Section of Fish Ladder prepared by NWEDC's Design Engineer (DKJV)

5 Upstream migrating challenges not connected to the fish ladder

A fish ladder might be well designed and well-built but the success depends on the conditions in the river downstream the fish ladder and of technical solutions of the entrance area and exit area of the fish ladders.

- The conditions at the confluence of the tailrace and the river should be paid attention so as the upstream migrating fish easily find the old riverbed.
- The dewatered river section should be examined for possible obstacles that might hinder upstream fish migration during the period of minimum flow release.
- The river section just downstream the weir should be adapted to the behavior of the migrating fish species so as the upper part of the fish migrating section meet the fish ladder entrance, see paragraph 3.1.
- The water level in the pool of the fish ladder entrance will by existing design fluctuate between 1229.1 (5m^3/s) to 1,231,5 (154.4m^3/s). Fluctuations of up to 2,4m might lead to challenges concerning fish migration.

6 Downstream fish migration

When making an investment in an expensive fish ladder to keep the upstream eco-corridor open, it requires mitigating actions to also keep the sustainability of the downstream eco-corridor. If the mortality of downstream migrating fish is high, the eco-system services will suffer, and over a relatively short time span the fish population using this eco-corridor will be decimated or extinct. If the mortality of downstream migrating fish is high and if mitigation of these harmful effects has low success it is better not letting the fish migrate upstream through a fish ladder.

To prevent a damaging fish population development the following topics should be considered:

1) Current in the intake pond
The main surface current entering the intake pond and weir should preferably point at the spillway See figure 10. The reason is that downstream adult fish probably migrate downstream in the main current during monsoon.
If needed a current guiding mechanism could be designed.

A question raised is if the fish ladder might be an attractive point to enter for downstream migrating fish. Due to the low flow in the fish ladder compared to the flow entering the settling basin a fish ladder would not serve as a suitable downstream migrating corridor.

2) Pool downstream of the weir
An important point is that fish migrating downstream across the weir should follow a smooth spillway and meet a soft landing in a downstream pool (see Sweco report of 15.08.2016, Fish Passage, evaluation of plans and recommendations, chapter 2.4).
The designed pool downstream the UT-1 weir does not serve as a soft-landing area for downstream migrating fish that are passing through the flapped gates.
When the flapped gates as designed at the top of the radial gates are used, they might serve as an opportunity for downstream migrating fish to pass over the weir. This will lead fish to fall 15 m and then hit the concrete basement. Heights above 5m will led to increased injurie and mortality. (see illustration, attachment 2). With a free fall of 15 m the fish will reach a velocity that even if hitting a water surface there will be high grade of injurie and mortality. To reduce the frequency of fish mortality due to passing through the flapped gates during monsoon, it is recommendable to use the flapped gates only short periods and to direct the excess water to a spillway at the left side of the weir, see figure 10. It might also be a positive solution to put one or more flapped gates at the top of the spillway as indicated in figure 10.

3) Tunnel entrapment
During low flow season and during early and late monsoon most of the flow are passing through the power station. In these periods most of the down migrating fish, fry and eggs also follow the flow to the settling basins before they enter the HP tunnel and the point of no return. Francis turbines show relatively high fish mortality, but it is a hope that fry and eggs have a reasonable survival rate. To reduce this mortality significantly a possibility might be to prepare fish guiding mechanisms in the settling basins. In the settling basins, the water velocity is slow which normally give good conditions for building guiding mechanisms.

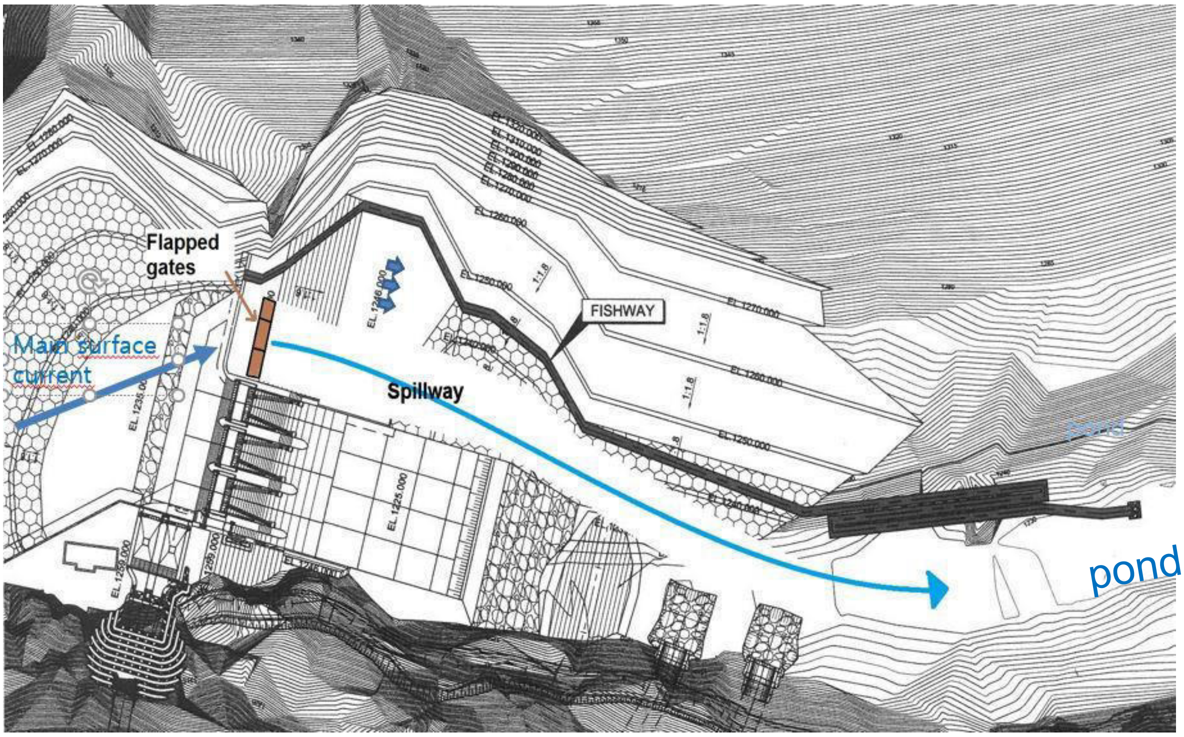


Figure 10 Upstream and downstream fish migration possibilities across the Upper Trisuli dam.

For more detailed information and discussions connected to the upstream and downstream migrations se the Sweco report of 15.08.2016.

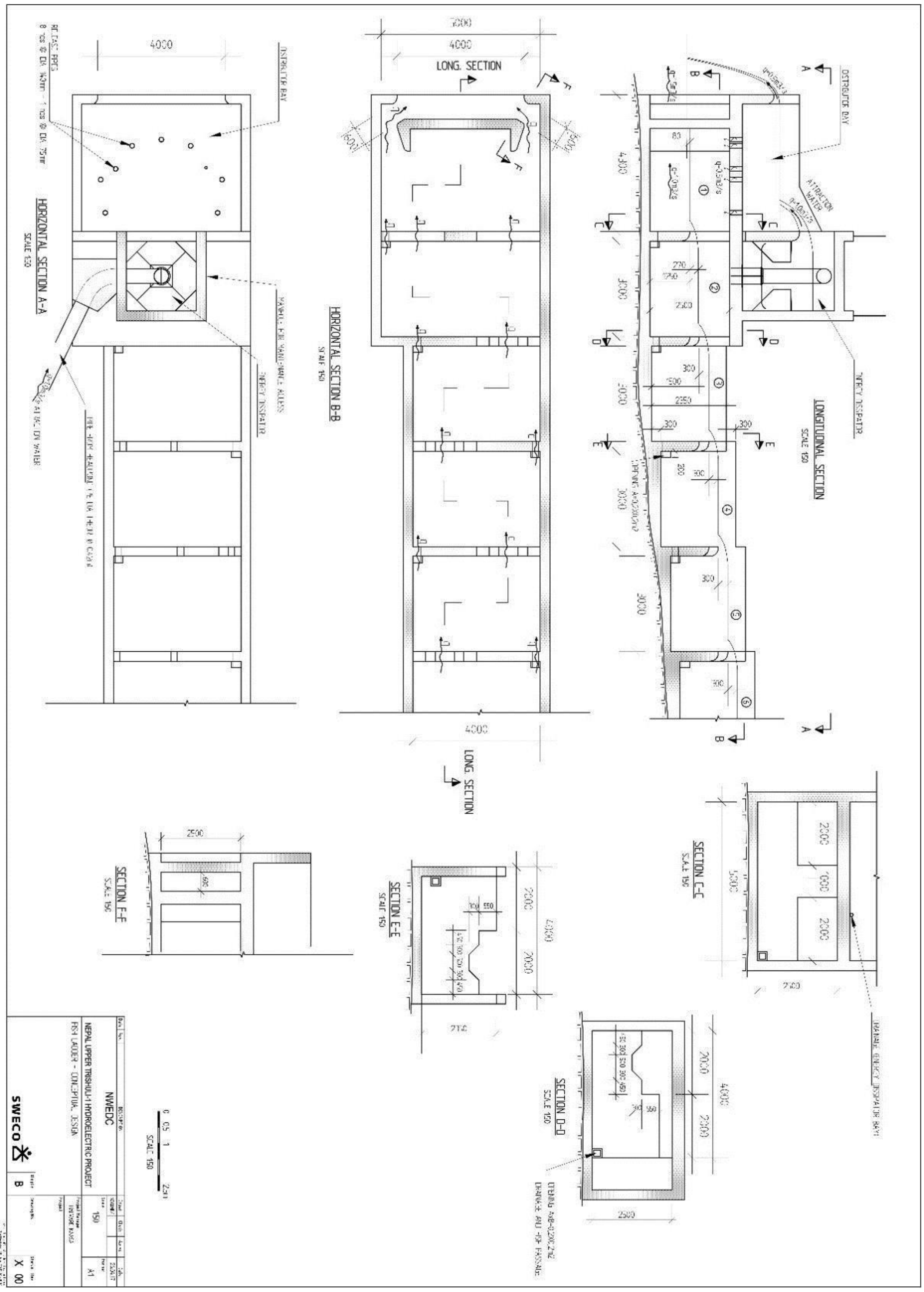
Some recommendations concerning the **management of the fish ladder:**

- High resolution flow data and temperature data will be good fish ladder management tools. Hourly flow data of a wet year, a medium wet year and a dry year, and hourly water temperatures give ability to understand functionality according to timeline and to be able to recommend technical solutions for the inlet and the outlet of the fish ladder.
  The fish do not respond to average values of flow and temperature.

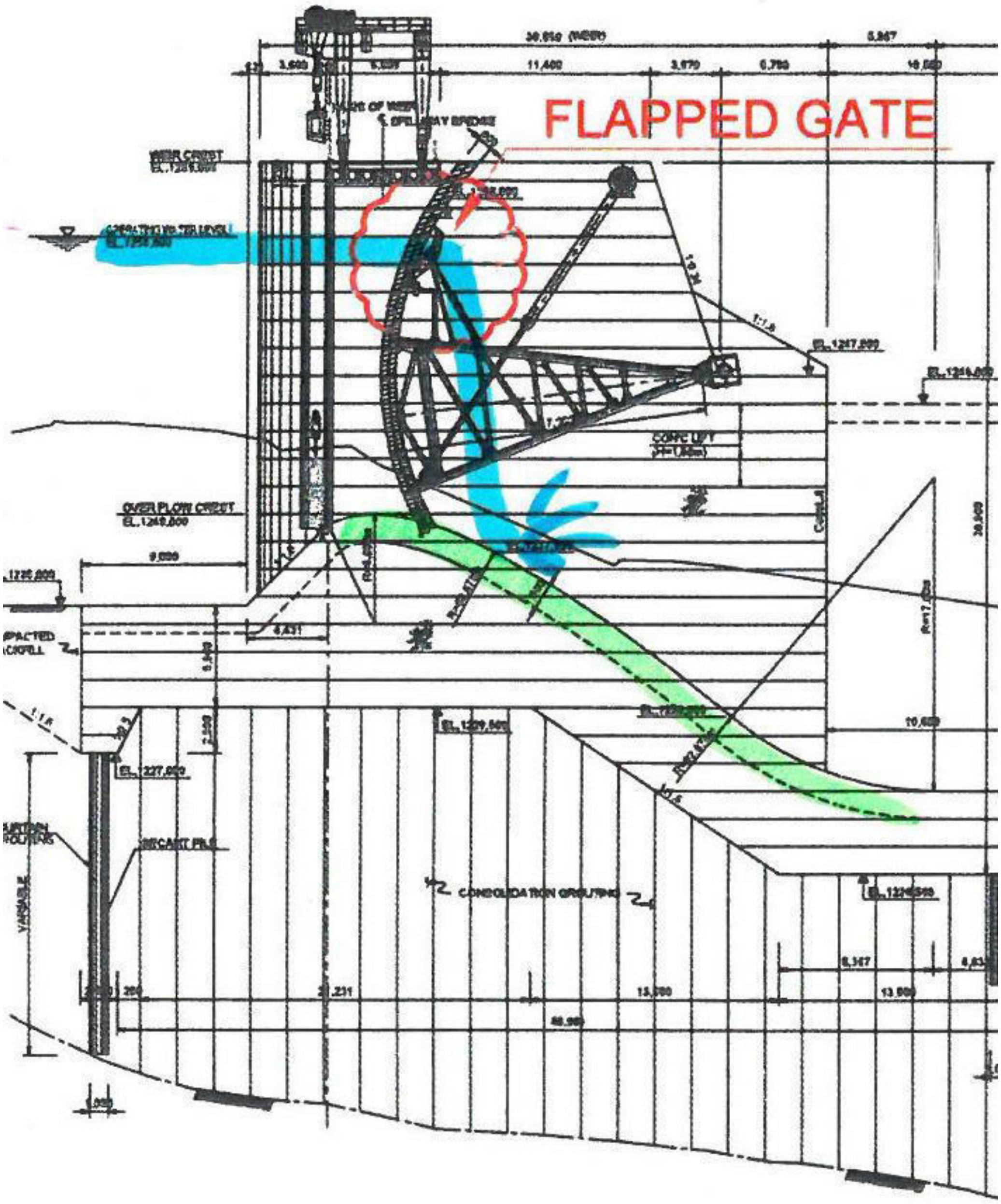
- Detection of the upstream fish migration season is important to decide technical solutions of the fish ladder entrance and for the management plan as operating periods of the fish ladder.

- Detection of the downstream fish migration will give good basis for management recommendations. The fish migrations are probably fluctuating between years and are probably related to temperature. Until better data of fish migration is available it is not possible to restrict the fish migration period to the low flow situation.

Attachment 1. Conceptual fish ladder design, made by SWECO.



Attachment 2. **Illustration of overflow trough flapped gates at the top of the radial gates.**



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Appendix E
Scenario-Based Evaluation of Flow Impacts on S. richardsonni in the Trishuli River

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Nepal Water and Energy Development Company (NWEDC) Limited

Naxal, Kathmandu

A Final Report

on

Upper Trishuli-1 HEP, Nepal: Scenario-based evaluation of flow impacts on *S. richardsonii* in the Trishuli River

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Executive Summary

Nepal has a huge potential for hydropower development. After the introduction of Hydropower Development Policy, 2001 there has been active involvement of private sector in hydropower development of Nepal. Most of the projects are being constructed by the local hydropower developers whereas some of the projects with greater installed capacities are being developed under the financial assistance by international funding agencies such as the World Bank and Asian Development Bank.

The Upper Trishuli-1 Hydroelectric Project (216 MW) is a Run-of-River type project being developed by Nepal Water and Energy Development Company (NWEDC). The project is funded by the International Finance Corporation (IFC). As a requirement of sustainable hydropower development and to meet the performance standards of IFC with regards to biodiversity conservation, an Eflows assessment followed by formulation of Environmental Flows Management Plan (EFMP) is carried out.

The Eflows assessment is carried out at three sites, viz.: upstream of dam site, in the dewatered river reach and downstream of the powerhouse site. About 12 km of the dewatered river reach is considered for eflows assessment. DRIFT model developed by Southern Waters is used to study the consequences of flow alteration due to project development on the life of *Schizothorax richardsonii*. Thus, the ecosystem indicators that are likely to be influential in the life of *S. richardsonii* as a result of flow changes are considered in this study. Similarly, baseline ecological status of each study site is evaluated and possible ecological changes of these sites due to flow alteration after the hydropower project is in place are evaluated.

The results of the study shows that the baseline ecological status of eflows site 1 (upstream of dam site) and site 3 (downstream of powerhouse site) are not changed significantly and seems to have minimum effect on the life of *S. richardsonii*. On the other hand, the ecological integrity and fish populations will be impacted in the dewatered river reach due to flow diversion for power generation. However, with the provision of efficient and functional fish passage the effects can be minimized. The results of the EFlows assessment also show that the best EFlows scenario for the *S. richardsonii* is the release of more water during the winter (low flow) months. However, power generation will be negatively impacted with the release of more water, with a loss of approximately 4.9 % of power if 20% of mean monthly flow is released. And, it is highly unlikely that the project will be financially viable with this power loss.

As NWEDC has exhibited commitment to biodiversity management for UT-1 through extensive baseline data collection, inclusion of a fish ladder that will meet international standards, a cumulative impacts assessment and this EFlows assessment, release of agreed eflows followed by appropriate mitigation measures during the project implementation shall be recommended for reducing the impacts on *S. Richardsonii* in the dewatered river reach.

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Acronyms

DRIFT	Downstream Response to Imposed Flow Transformation
EFlows	Environmental Flows
EFMP	Environmental Flows Management Plan
HEP	Hydroeletric Project
IFC	International Finance Corporation
NWEDC	Nepal Water and Energy Development Company
VDC	Village Development Committee

1 Introduction

1.1 Background

1.1.1 The Trishuli River

The Trishuli River is a trans-boundary river and is one of the eight sub-basins of the Gandaki River basin in Central Nepal. It covers an area of 32 000 km^2, which is 13% of the total Gandaki area. The Trishuli watershed lies within the physiographic Highland and Midland zones defined by average altitudes of ~2000 m and high valley landscapes.

The Trishuli River originates in the Tibet Autonomous Region of the People's Republic of China, where it is known as Bhote Koshi. The catchment area of Bhote Koshi in Tibet is ~3 170 km^2 for a river length of 120 km. The ~106 km of Trishuli River within Nepal shows a high gradient in the initial 40 km with rapids dominating the longitudinal profile but there are no impassable falls (CIA UT-1, 2014, ESSA).

1.1.2 The Project

The proposed Upper Trishuli-1 HEP (216 MW) is a 'Run-of –River' type project being developed by Nepal Water and Energy Development Company (NWEDC) Ltd. The main project features are the headworks (including diversion weir, intake, and diversion tunnel), desander basin, headrace tunnel (including surge tank, vertical shaft) and powerhouse, including the tailrace tunnel. The project is located in Rasuwa District, Bagmati Zone 80 km northeast of Kathmandu. The intake site is located at Hakubesi of Haku VDC and powerhouse site at Mailun of Haku VDC. The catchment area at the intake site is 4 350.88 km^2 and the design discharge at Q51 is 76 m^3/s. By utilizing the net head of 333.93 m, an average annual energy of 1533.1 GWh could be produced. The total project cost is estimated to be around US$ 382.583 Million and is expected to be completed within 5 years from the start of construction. The location map of Upper Trishuli-1 HEP is given in Figure 1.1.

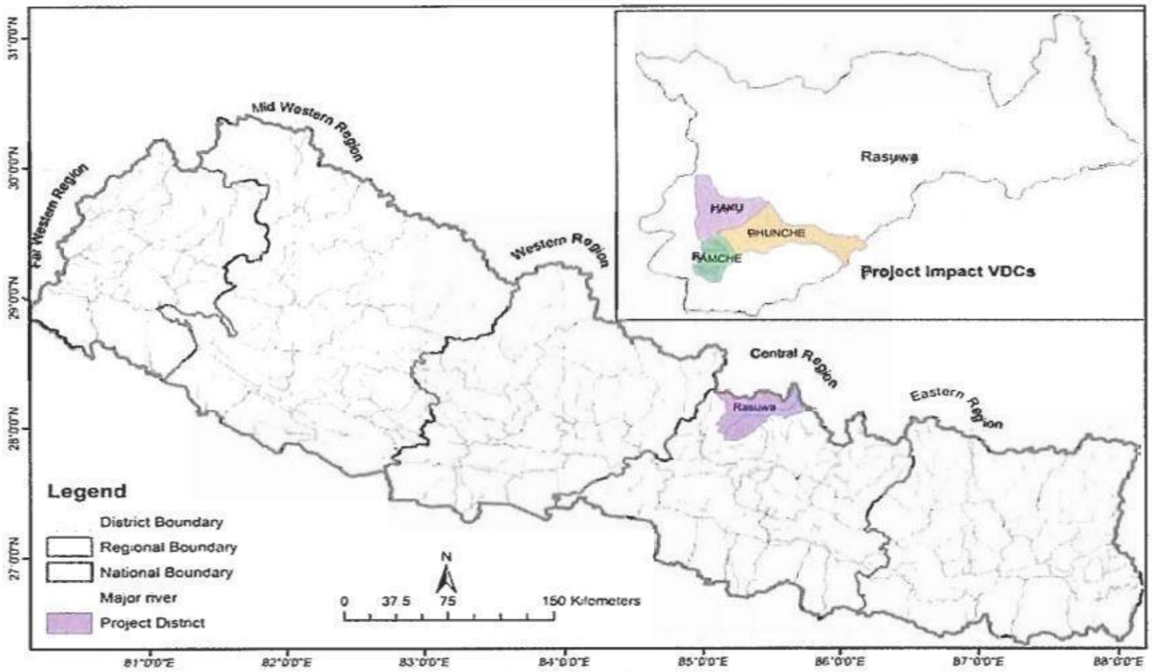


Figure 1.1 Location of Upper Trishuli-1 HEP, Nepal (Approved EIA Report of UT-1 HEP)

The design features of the project are shown in Table 1.1.

Table 1.1 Upper Trishuli-1 HEP design features (NWEDC)

Item	Description
Catchment area at intake site	4350 km^2
Design Discharge at Q51	76 m^3/s
Net Head	324 m
Plant Capacity	216 MW (72 MW x 3 units)
Average Annual Energy	1 533.1 Gwh
Saleable Energy	1 456.4 Gwh
Diversion Structure	Concrete Gravity Dam/Weir of height 32.0 m and overall length of 100.90 m.
Intake	2 Nos. each of 3.25 m wide and 6.5 m high
Desanding basin	Underground(3 chambered) with effective length of 115 m
Headrace Tunnel	9.715 km long, 6.5 m diameter
Surge tank	292 m deep, 8.5 m diameter on top, restricted orifice type
Tailrace tunnel	178 m long, 6.5 m diameter
Penstock	3 steel lined penstock tunnels
Powerhouse	Underground

1.2 The EFlows assessment

1.2.1 Terms of Reference

The contract agreement for preparation of Environmental Flows Management Plan (EFMP) of UT-1 HEP between Nepal Water and Energy Development Company (NWEDC), the client and S.A.N. Engineering Solutions Pvt. Ltd. (the consultant) was signed between the two parties based on the following Terms of Reference.

(i) Introduction

As a part of process to ensure compliance of the Upper Trishuli-1 Hydroelectric Project (UT-1HEP) with Nepal national regulations and the IFC's Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Resources, NWEDC is required to develop environmental flow management to maintain viable populations during construction and operations of the Upper Trishuli-1 Hydropower Project.

(ii) Objectives

In line with IFC's Performance Standard, the objective of this scope of work is to develop an Environmental Flows Management Plan (EFMP) to maintain viable fish populations during construction and operations of the Upper Trishuli -1 Hydroelectric Project (UT-1 HEP), Nepal.

(iii) Approach to the study

The Consultant's effort was streamlined to meet the objectives as outlined by the Scope of Work.

The Hydropower Development Policy (HDP 2001) is the guiding document for EFlows releases in the design of hydropower projects in Nepal. According to HDP, a developer is required to release 10% of the minimum monthly average flow or the quantum stated in the Environment Impact Assessment (EIA) Report, whichever is higher, as a minimum flow criterion. This minimum flow, in fact, does not constitute an EFlows provision as it does not consider the aquatic ecosystem in the study reach, nor any potential knock-on effects downstream of that reach. With the involvement of donor agencies such as Asian Development Bank and the World Bank Group in hydropower development in Nepal, however, there has been a growing concern about ensuring sustainable hydropower development and adherence to the performance standards of these donor agencies.

The Consultant will develop EFMP for UT-1 HEP to meet IFC Performance Standard 6, i.e., no net loss of biodiversity. That said, the timing and other limitations that define the study necessitate a rapid approach that focuses on the mitigation of any residual impacts on *Schizothorax richardsonii* with a 10% of minimum monthly average flow release in place and a reliance on existing information, including unpublished relationships between *S. richardsonii* and flow established for similar rivers in the Himalayan region. To this end, the evaluation of flow scenarios comprising different minimum flow releases will be done used the DRIFT Method (Brown *et al*. 2013), which has been successfully implemented in the Neelum/Jhelum Basin in Pakistan-administered Kashmir.

The key questions addressed were:

- At what time of the year, and in what part of its life cycle, does *S. richardsonii* utilise the study reach?
- Does a minimum release of 10% of minimum monthly average flow adversely affect *S. richardsonii*'s migration and, by inference, its breeding success?
- If so, is it possible to implement a regime whereby the flow is increased beyond 10% of minimum monthly average flow releases during certain days in the period March to May to mitigate any potential negative impacts to the onset of upstream migration as well as to reduce potential impairment of the overall spring upstream migration process, while maintaining economically-viable power generation?

Evaluation of the above was based on the assumption that there were no major negative impacts to the river morphology and/or spawning sites that could either impede or improve migration and/or spawning. An additional question related to whether or not changes to stream channel morphology as a result of the various flow rates evaluated would directly or indirectly alter physical habitats used by *S. richardsonii*, and whether there is any scope to improve existing habitat downstream of UT-1 HEP.

The results of the evaluations will inform discussion and agreement on an EFlows regime for the study reach, which will then form the basis of the EFMP.

The EFlows assessment focuses on three sites, viz.: upstream of UT-1 HEP, the dewatered reach and downstream of the tailrace as indicated in Figure 1.2. The other two sites, one at headworks of Mailun Khola Hydropower Project and the other at confluence of the Trishuli River and Mailun Khola were considered simply as the places where snow trout migrate to and from.

Figure 1.2 Study area for the Upper Trishuli-1 HEP EFlows assessment

The sites marked 1, 2 and 3 are located upstream of the dam, in the dewatered section and downstream of the powerhouse, respectively.

1.3 Limitations of the study

The level of detail achieved in this assessment is commensurate with available data and information, budget and programme. Thus, although the process applied in this assessment is similar to that used in more detailed EFlows assessments, it is a coarse-level assessment, with the focus on the identification of major risks to the ecosystem associated with the Upper Trishuli HEP using responses to flow and sediment changes developed for a different but similar river.

The following exclusions, limitations and assumptions apply:

- The study:
    - focuses on *S. richardsonii*
    - uses existing information
    - excludes any hydraulic modelling or topographical survey of the study reach
- Changes to stream channel morphology are evaluated qualitatively only.
- Scenarios include UT-1 HEP only.

The Client provided the following:

- 20-30 years daily flow data for pre-UT-1 conditions in the study reach.
- Flow regime, including spills, with UT-1 HEP in place with a minimum monthly average release of 10%, covering the same period as the per-UT-1 hydrological time-series.
- Information related to sediment supply to and deposition in the UT-1 reservoir.
- Operational rules related to flushing sediments.
- The number of scenarios evaluated is limited to six, plus baseline.
- Offsets were not evaluated in terms of feasibility, effectiveness or cost, and detailed design was not be undertaken
- Stakeholder engagement was excluded

Finally, data are always a limiting factor in environmental studies. With contemporary understanding of how aquatic ecosystems function, it has become easier to predict what will change and the direction of change. It is less easy to predict by how much ecosystem components will change and how long it will take. For this reason:

- all predictions should be evaluated with due cognizance of the assumptions necessitated by the constraints of the study; and
- it is better to evaluate the outcome of the scenarios relative to one another rather than as absolute individual predictions of change.

2 EFlows sites

An EFlows assessment was carried out at three sites, *viz.*: upstream of the dam site, dewatered river reach and downstream of the powerhouse. Due to the diversion of flow from intake, natural flow conditions in the section of the river between the dam site and the power house site will be impaired. This impairment is greatest in the dewatered river reach, but there will also be effects at upstream of the dam site and downstream of the tailrace. Thus, the EFlows study considered the three sites shown in Figure 1.2. The locations of these sites are as follows:

i) Site 1: 28° 07' 36.40"N, 85° 17' 52.41"E Upstream of Dam site
ii) Site 2: 28° 05' 27.76"N, 85° 14' 7.87"E Dewatered Zone
iii) Site 3: 28° 04' 13.87"N, 85° 12' 28.63"E Downstream of Power House Site.

Since the EFlows sites 1 and 3 are located close to the headworks site and the powerhouse site respectively, the length of the river that was considered for the eflows study is approximately 12 km. As mentioned in the Terms of reference for EFMP formulation, the dewatered river reach was only considered for the eflows assessment.

3 Hydrology

The baseline hydrological and scenario daily time-series data were provided by NWEDC. These are based largely on flow data obtained from the Department of Hydrology and Meteorology (DHM) gauging station at Betrawati, located 12 km D/s of intake. The best available long-term hydrological data were for the period 1967 to 2013, and so this was the period on which the EFlows assessment was based.

Details of the hydrological data available for the Upper Trishuli River and the procedures undertaken to obtain then are covered in **Hydrological Analysis of Detail Design Report-II, Civil of UT-1 HEP**.

The hydrological record for the Trishuli River suggests that this is a flood-pulse system, with four well-defined seasons (Figure 3.1). Figure 3.2 provides some examples of the year-on-year variation in flow and flow seasons at one of the EFlows sites. The seasonal divisions shown in these figures are those identified in DRIFT using the parameters listed in Table 3.1.

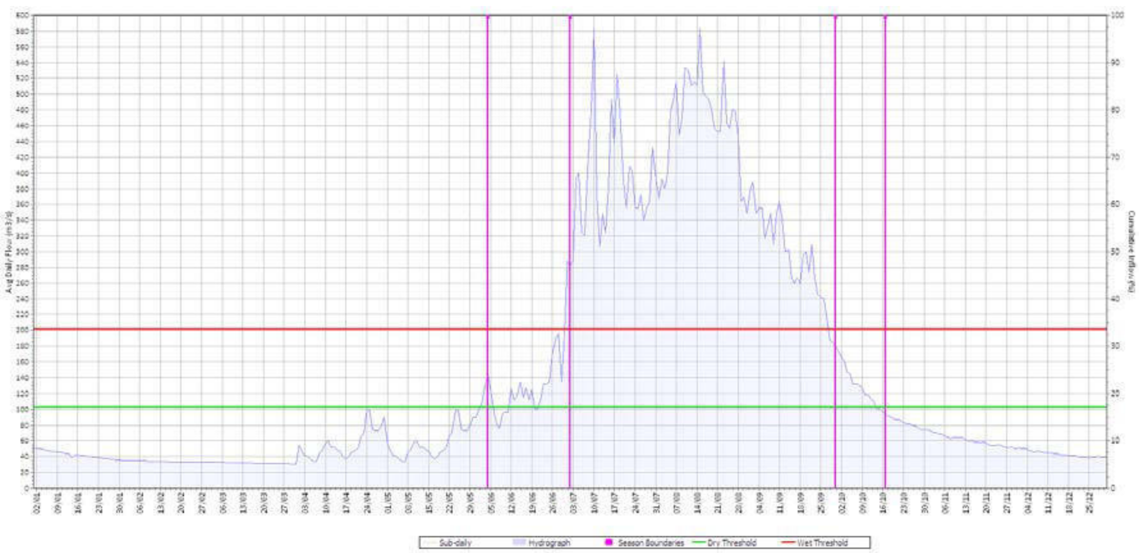


Figure 3.1 One year (1967) of the baseline hydrological record at Site 2, showing the seasonal divisions, from left to right, into: Dry, Transitional 1, Wet, Transitional 2, and back into Dry.

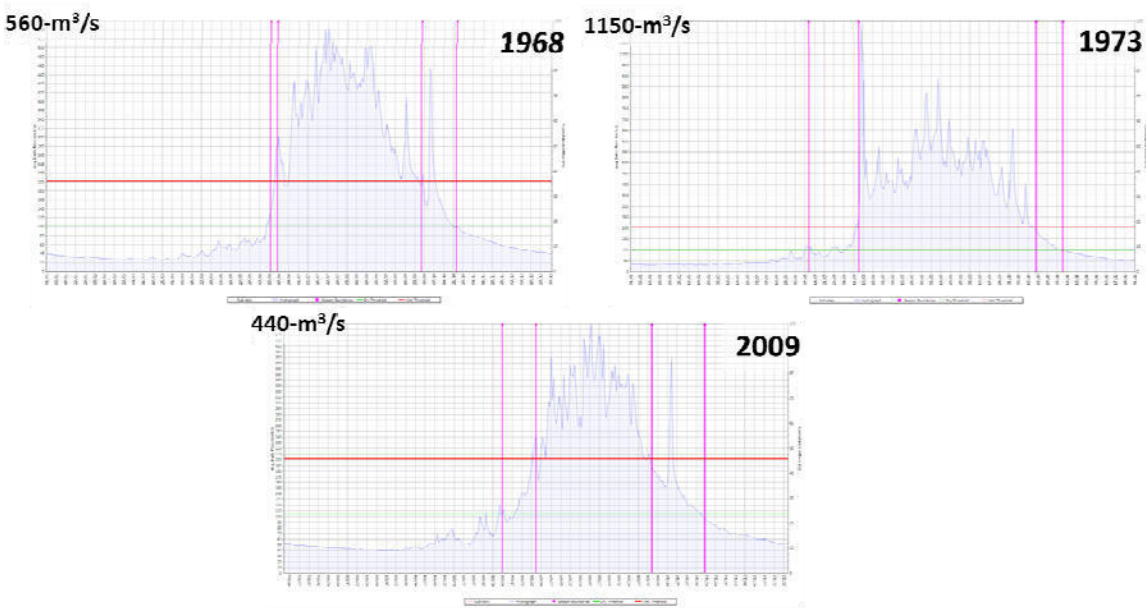


Figure 3.2 Examples of year-on-year variation in flows and flow seasons in the baseline time-series at Site 2. The maximum discharge is indicated at the top left of each example.

Table 3.1 Parameters used for seasonal divisions

Division	Parameter
Start of the hydrological year	January
End of Dry season	4 x minimum dry season discharge
Start of Wet season	1.1 x mean annual discharge
End of Transition 2	4 x minimum dry season discharge, and the recession rate < 0.1 m^3/day over 10 days

Once the seasons were defined, DRIFT calculated a suite of ecologically-relevant flow indicators that were used by the specialists to determine the flow-related links to the ecosystem indicators (Section 7). The flow indicators and the reasons for their selection as indicators are given in Table 3.2. Each flow indicator was calculated for each year in the hydrological record, thereby deriving an annual times-series of 47 years for each flow indicator (see examples in Figure 3.3).

The flow indicators are used as drivers of change in other aspects of the river ecosystem. They are reported in the results to provide context for and understanding about the ecosystem responses. They are not used in the calculation of ecosystem integrity.

Table 3.2 Flow indicators used in the Upper Trishuli River

Indicator	Reason for selection as indicators
Mean annual runoff	Gives an indication of annual abstraction/addition of water, if any.
Dry season minimum 5-day discharge	Dry season minimum 5-day average flows influence available habitat area, fish movement, and winter temperatures (buffering)
Dry season onset	Onset and duration of seasons: • link with climatic factors • cues fruiting and flowering • cues migration/breeding • support life-history patterns.
Dry season duration	The dry season is typically the harshest season for aquatic life to survive. This is the time when flows are low, water quality influences potentially stronger and temperatures (either hot or cold) are most challenging. Increases in the duration of this harsh period can have significant influence on overall chances of survival.
Dry season average daily volume	Dry periods • promote in-channel growth • support larval stages • maintain intra-annual variability.
Wet season onset	Onset and duration of seasons: • link with climatic factors • cues fruiting and flowering • cues migration/breeding • support life-history patterns.
Wet season duration	Important for supporting life-stages, such as hatching and growth of young. The wet season is also when most erosion and deposition occurs due to the higher shear stress and sediment loads in the river.
Wet season flood volume	Floods: • dictate channel form • flush and deposit sediment and debris • promotes habitat diversity • support floodplains • distribute seeds • facilitate connectivity • control terrestrial encroachment.
Transition1 and Transition2 average daily volume	Dry-wet-dry transitions: • distribute sediments and nutrients flushed from the watershed • distribute seeds • support migration of adults and larvae
Transition 2 recession slope	Transition 2 recession shape refers to the speed at which the flows change from wet season flows to dry season flows. Under natural conditions this is usually a relatively gentle transition, but this can change with impoundments. If it is a very quick transition then there can be issue of bank collapse and/or stranding similar to those described for 'within-day range in discharge'.

Flow changes in the dry and transition seasons are included as this when water resource infrastructure has the potential to exert a large effect on water-level fluctuations. The Trishuli Scenarios did not include consideration of peaking-power operations. Had this been necessary then additional flow indicators linked to within-day range in discharge: Wet, transition and dry seasons would also have been selected. Changes in water level over short periods are important for a number of reasons:

- the shear stress changes rapidly as flow rate changes affecting both the water surface slope and the depth of the river. Thus conditions, for erosion but also for animals and plants, change rapidly over this time, often to a point where they can no longer maintain their position in the channel, resulting is wash-away.
- rapid decreases flow can also lead to stranding of animals as flows recede from an area quicker than the animals can respond.
- as water levels decrease, riverbanks may not drain as quickly as the river recedes, leading to an over pressuring within the banks that reduces bank stability.

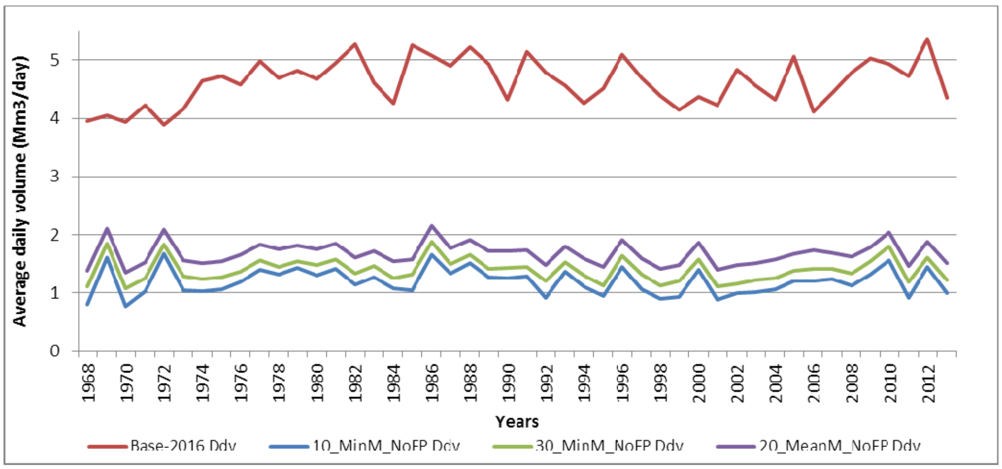


Figure 3.3 Examples of annual time-series of a DRIFT flow indicator: average daily volume in the dry season (showing four scenarios).

4 Life history considerations – *Schizothorax richardsonii*

Schizothorax richardsoni, which is locally known as the snow trout or Asla (together with other *Schizothorax* species) is found in the rivers and streams of mountainous areas of the Himalayas, India, Afghanistan and Nepal.

It is listed as Vulnerable in the IUCN Red Data List (www.iucnredlist.org). The justification provided is: "*Although S. richardsonii is widely distributed along the Himalayan foothills and previous studies have indicated that it is abundantly and commonly found, 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. While in some areas the declines are more than 90%, the overall reduction is inferred to be less than 50% with similar rates predicted in the future. The species is therefore assessed as Vulnerable. However, there is a strong belief that if alien species introductions are carried out throughout its range, this species may completely be displaced by exotic salmonids*" (Vishwanath 2010).

S. richardsonii prefers to live among rocks and is primarily a bottom feeder, preferably near big submerged stones. It is mainly herbivorous, feeding mainly on algal slimes, aquatic plants and detritus, but also aquatic insect larvae encrusted on the rocks (Vishwanath 2010). Asla has two spawning periods (March-April and October-November). It migrates from lakes and rivers of the valley to the adjoining tributaries to find suitable places for breeding, mainly in side streams or a side channels along the main river bed (Jhingran 1991; Welcomme 1985 and Sunder 1997).

A summary of key life history aspects of *S. richardsonii* is provided in Table 4.1.

Introduction of exotic salmonids, such as Rainbow Trout, in hill streams and reservoirs of the Himalayan foothills are a serious threat to the survival of *S. richardsonii*. Fishing for ornamental trade is also a threat in Nagaland and they are widely utilised as food (Vishwanath 2010).

4.1 Presence of *S. richardsonii* at EFlow Site 1 and 2 in winter

One of the key aspects of snow trout life history of relevance for this project is its temperature tolerances. Some studies suggest that *S. richardsonii* will not be found in the upper reaches of Himalayan rivers in the cold winter months (e.g., Shrestha 1990; Sivakumar 2008; Talwar and Jhingran 1991) as it has a low tolerance for temperatures lower than 7-10°C (Shrestha and Khanna 1976, http://nmcg.nic.in/BioFish.aspx). However, *S. richardsonii* was recorded in the vicinity of EFlow Site 1 and 2 in this study (Kaasa, 2015), and in the EIA for the Upper Trishuli-1 HEP (Approved EIA, Feb. 2013), in the winter at temperatures of ~7°C.

Table 4.1 Summary of key life history aspects of *S. richardsonii*

Habitat, food and temporal pattern		Juveniles		Adults (non-breeding)		Spawning	
		Information/ data	References	Information/data	References	Information/data	References
Habitat and flow preferences	Description of habitat	-	-	Found in rivers and streams of mountainous areas of the Himalayas, India, Afghanistan and Nepal	Menon (1999); Sunder et al. (1999); Talwar and Jhingran (1991)	Clear water on gravelly/stony grounds or on fine pebbles (50-80 mm diameter)	Shrestha and Khanna (1976)
	Altitude	-	-	In Trishuli River, snow trout abundant in the 1875 m-3125 mamsl zone and prefers rapid, pool and riffle types of habitats.	IUCN Red List of Threatened Species (Vishwanath, W.)		
	Substrate	Stones and gravels	Raina and Petr (1999)	Rocks and big submerged stones	IUCN Red List of Threatened Species (Vishwanath, W.)	Developing eggs and larvae have been seen in semi-stagnant nursery beds along riverbanks interspaced with gravel and stones.	Raina and Petr (1999)
	Depth	<0.75 m	Shrestha and Khanna (1976)	1-3 m	http://nmcg.nic.in/BioFish.aspx	1-3 m	Shrestha and Khanna (1976)
	Velocity	0-2 m/s	Shrestha and Khanna (1976)	2-8.4 m/s	http://nmcg.nic.in/BioFish.aspx	2-8.4 m/s	Shrestha and Khanna (1976)
	Temperature	10-18 0C	Shrestha and Khanna (1976)	7.2-22 0C	http://nmcg.nic.in/BioFish.aspx	12-15 0C	Shrestha and Khanna (1976)
	Dissolved O2	6-8 mg/l	http://www.fao.org/docrep/005/y3994e/y3994e0q.htm	6-8 mg/l	http://www.fao.org/docrep/005/y3994e/y3994e0q.htm	10-15 mg/l	Sunder (1997); Shrestha and Khanna (1976)
Food preferences		Invertebrates, algae		Omnivorous and opportunist feeder. Mainly algae, fish and invertebrates	Shrestha (1990); Jhingran (1991)	n/a	n/a

Additional information	Information/data	References
Migration	Snow Trout migrate upstream at the start of the monsoon season in March-April (gravel/pebble spawning and downstream at the end of this season in October-November for spawning	Shrestha (1990); Negi (1994); Talwar and Jhingran (1991)

<table>
<tr><td colspan="2" rowspan="2">Habitat, food and temporal pattern</td><td colspan="2">Juveniles</td><td colspan="2">Adults (non-breeding)</td><td colspan="2">Spawning</td></tr>
<tr><td>Information/ data</td><td>References</td><td>Information/data</td><td>References</td><td>Information/data</td><td>References</td></tr>
<tr><td>Triggers</td><td colspan="5">Breeding is triggered by snow melt and rise in turbidity. Fish move to breeding grounds in shallow side pools, side-channels and tributaries of the river with cobbles and gravely beds. Eggs hatch in this season, and fries and fingerlings remain in shallow waters in side channels</td><td colspan="2">Jhingran (1991); Welcomme (1985); Sunder (1997)</td></tr>
<tr><td>Spawning behaviour</td><td colspan="5">Snow Trout spawns when two years old, depending on food supply. Mature Asla has a change in colour during the breeding time. Mature males develop tubercles on either side of the snout, faint yellow colour of the body, and reddish colour of fins. Females spawn in natural as well as in artificial environments. S. richardsonii can spawn naturally or by stripping the wild/cultured mature female during the spawning season. It spawns in September/October and March/April.</td><td colspan="2">http://www.fao.org/docrep/005/y3994e/y3994e0q.htm</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>Months</td><td>Flow Conditions</td><td colspan="4">Fish Behaviour</td><td colspan="2">References</td></tr>
<tr><td>May/June</td><td>Onset of flood season</td><td colspan="4">Snow Trout spawns in spring. By this time of the year, the fish eggs reach to its final stage of maturity provided the aquatic system provides sufficient food required for proper development of eggs. Once the eggs reach to their final stage of maturity, the fish is ready to spawn under various triggers like the snowmelt, rise in water temperature, comparatively higher turbidity level, swelling of rivers, creation of side channels etc. mainly linked with the monsoon rains and snow melt in the upper reaches of the Himalayan rivers</td><td colspan="2">Negi (1994); Rafique and Qureshi (1997); Talwar and Jhingran (1991)</td></tr>
<tr><td>October November</td><td>Onset of winter season</td><td colspan="4">Snow Trout migrates downstream during winter as water temperatures decline in the upper reaches of the rivers, and may spawn again at this time. It is not found in the upper reaches of the rivers in the cold winter months</td><td colspan="2">EF Assessment UT-1 HEP, ESSA, Nov. 2014; Shrestha (1990); Sivakumar (2008); Talwar and Jhingran (1991)</td></tr>
</table>

5 Ecosystem indicators

Ecosystem indicators are comprised of riverine components that respond to a change in river flow (or sediment) by changing their abundance; concentration; or extent (area).

The focus of this assessment is *S. richardsonii* and so the ecosystem indicators selected to capture the response to changes in water flow and longitudinal connectivity are limited to those considered to be most influential in the life history of *S. richardsonii.* Thus, the supporting ecosystem indicators focus on *S. richardsonii* habitat and food.

The ecosystem indicators and the reasons for selection are provided in Table 5.1.

Table 5.1 Ecosystem indicators

Discipline	Indicators	Reason for selection as indicators
Geo-morphology	Suspended sediment load	Suspended load is important for creating and maintaining various habitats.
	Exposed sand and gravel bars	Sand and gravel bars during provides habitat for invertebrates and fish.
	Exposed cobble and boulder bars	Cobble and boulder bars provide habitat for invertebrates and fish.
	Median bed sediment size (armouring)	The average size of river bed sediment is an important habitat component for many fish species.
	Area of secondary channels, back waters	Secondary channels and backwaters provide important instream habitat for many fish species. These slower velocity areas, usually with well-developed marginal vegetation, act as refugia for juvenile fish.
Algae	Algae	*S. richardsonii* feeds on algae and invertebrates
Macro-invertebrates	EPT abundance	*S. richardsonii* feeds on algae and invertebrates
Fish	Snow trout (*S. richardsonii*) abundance	*S. richardsonii* is listed as Vulnerable in the IUCN Red Data List. It is widely distributed along the Himalayan foothills (India, Afghanistan, Pakistan, Nepal), but drastic declines have been recorded over the last 5 to years in many areas of its range due to: • introduction of alien species, • damming, and • overfishing.

Each indicator is linked with other indicators deemed to driving change. The aim is not try to capture every conceivable link, but rather to restrict the linkages to those that are most meaningful and can be used to predict the bulk of the likely responses to a change in the supply of water, sediment or longitudinal connectivity.

6 Ecological Status

The scores and descriptions for Ecological Status categories are provided in Table 6.1.

Table 6.1 Categories for Baseline Ecological Status (after Kleynhans 1997)

Ecological category	Description of the habitat condition
A	Unmodified. Still in a natural condition.
B	Slightly modified. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged.
C	Moderately modified. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	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 changed and the changes are irreversible.

6.1 Baseline Ecological Status of the EFlows sites

The Baseline Ecological Status (BES) used for the Trishuli River in this assessment is summarised in Table 6.2.

Table 6.2 BES of the EFlows sites on the Upper Trishuli River at 2016.

Discipline	1	2	3
Geomorphology	A/B	A/B	A/B
Algae	B	B	B
Macronvertebrates	A/B	A/B	A/B
Fish	B	B	B
Overall BES	B	B	B

7 Response curves

The response curves do not address any of the scenarios directly. The curves are drawn for a range of possible changes in each linked indicator, regardless of what is expected to occur in any of the scenarios. For this reason, some of the explanations and/or X-axes refer to conditions that are unlikely to occur under any of the scenarios but are needed for completion of the Response Curves. In addition, each response curve has a shape that assumes that all other conditions (indicators) remain at baseline.

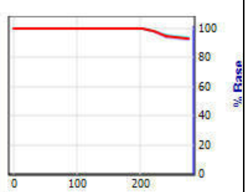
The relationships are similar across all areas, although the actual curves may differ slightly from what is shown here. For the exact relationship used for each focus area please refer to the DSS. The focus area used as an example is denoted in the caption.

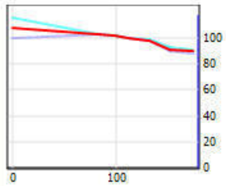
The response curves relationships used for this assessment were not derived specifically for the assessment for the Upper Trishuli River. They were derived for Alwan Snow Trout in similar Himalayan river (the Neelum-Jhelum River) and used in this assessment. Links to sediment supply were excluded from the DSS because the EFlows team was assured by the Client that the sediment regime upstream and downstream of Upper Trishuli HEP would remain at baseline levels. Rainbow Trout were also excluded from the assessment. This was because there were no curves for rainbow trout for the Neelum-Jhelum, and because rainbow trout in the study area are escapees from nearby trout farms.

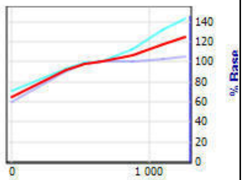
The linked indicators, the response curves and the explanations of the shape of the response curves for each of the indicators, using Site 2 as an example, are tabulated as follows:

Table 7.1 Exposed sand and gravel bars
Table 7.2 Exposed cobble and boulder bars
Table 7.3 Median bed sediment size
Table 7.4 Area of secondary channels and backwaters
Table 7.5 Algae
Table 7.6 EPT (Ephemeroptera, Plecoptera and Trichoptera)
Table 7.7 Snow *trout* - *S. richardsonii*.

Table 7.1 Exposed sand and gravel bars

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>☑ Dry season duration [D season]
<table>
<tr><th>Desc</th><th>days</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>154.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>179.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>204.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>222.000</td><td>-0.100</td><td></td></tr>
<tr><td>Max Base</td><td>240.000</td><td>-0.300</td><td></td></tr>
<tr><td>Max</td><td>276.000</td><td>-0.400</td><td></td></tr>
</table>

</td><td>During the dry season when sediment levels are low, finer sediment is scoured from the active channel, leading to a slow loss of sand/gravel bars. The longer the dry season, the more erosion of bars will occur.</td></tr>
</table>

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>☑ Wet season duration [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.500</td><td></td></tr>
<tr><td>Min Base</td><td>84.000</td><td>0.100</td><td></td></tr>
<tr><td></td><td>98.000</td><td>0.050</td><td></td></tr>
<tr><td>Median</td><td>112.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>131.500</td><td>-0.100</td><td></td></tr>
<tr><td>Max Base</td><td>151.000</td><td>-0.500</td><td></td></tr>
<tr><td>Max</td><td>173.650</td><td>-0.600</td><td></td></tr>
</table>


</td><td>Longer wet seasons mean a longer period of high flows with relatively lower sediment loads (in this river observed data suggest that the peak sediment loads generally occur early in the wet season, prior to peak discharge). Thus longer wet seasons may mean greater erosion (widening/deepening) in the main channel, causing some reduction of sand/gravel.</td></tr>
<tr><td>☑ Max 5d wet season Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>391.480</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>522.460</td><td>-0.100</td><td></td></tr>
<tr><td>Median</td><td>653.440</td><td>0.000</td><td></td></tr>
<tr><td></td><td>873.940</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>1094.440</td><td>1.200</td><td></td></tr>
<tr><td>Max</td><td>1258.606</td><td>1.500</td><td></td></tr>
</table>


</td><td>Larger floods are associated with higher sediment loads, and with widespread channel instability and reworking of the channel bed and banks. Large floods will thus introduce more sediment and create more sand/gravel bars during the flood season (which can be exposed as sand/gravel bars during the dry season).</td></tr>
<tr><td>☑ Dry season ave daily vol [D season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.000</td><td></td></tr>
<tr><td>Min Base</td><td>3.890</td><td>0.200</td><td></td></tr>
<tr><td></td><td>4.283</td><td>0.100</td><td></td></tr>
<tr><td>Median</td><td>4.675</td><td>0.000</td><td></td></tr>
<tr><td></td><td>6.286</td><td>-0.200</td><td></td></tr>
<tr><td>Max Base</td><td>7.896</td><td>-0.600</td><td></td></tr>
<tr><td>Max</td><td>9.081</td><td>-1.000</td><td></td></tr>
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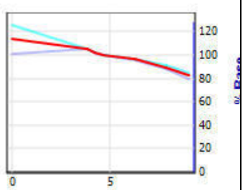

</td><td>Lower flows mean that more bars will be exposed.</td></tr>
</table>

Table 7.2 Exposed cobble and boulder bars

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>☑ Wet season duration [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.500</td><td></td></tr>
<tr><td>Min Base</td><td>84.000</td><td>0.500</td><td></td></tr>
<tr><td></td><td>98.000</td><td>0.100</td><td></td></tr>
<tr><td>Median</td><td>112.000</td><td>0.000</td><td></td></tr>
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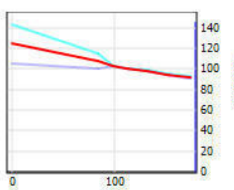

</td><td>Longer wet seasons mean a longer period of high flows with relatively lower sediment loads (in this river observed data suggest that the peak sediment loads generally occur early in the wet season, prior to peak discharge). Thus longer wet seasons may mean greater erosion (widening/deepening) in the main channel, with some potential loss of cobble bars.</td></tr>
<tr><td>☑ Max 5d wet season Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y1</th><th>Y2</th></tr>
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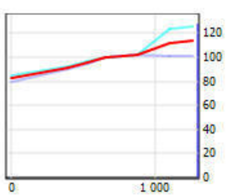
<tr><td>Max Base</td><td>1094.440</td><td>0.900</td><td></td></tr>
<tr><td>Max</td><td>1258.606</td><td>1.000</td><td></td></tr>
</table>


</td><td>Very large floods tend to redistribute sediments across the channel, and in rivers with a cobble matrix these events should enlarge existing and create additional bars. Very small floods may not overcome thresholds to redistribute bed sediments across the valley floor, allowing bars to over time be incorporated in to the bank.</td></tr>
<tr><td>☑ Dry season ave daily vol [D season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.000</td><td></td></tr>
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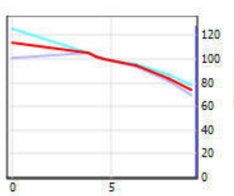

</td><td>Lower flows mean that more bars will be exposed</td></tr>
</table>

Table 7.3 Median bed sediment size

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
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☑ Max 5d wet season Q [F season]
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.000</td><td></td></tr>
<tr><td>Min Base</td><td>391.480</td><td>0.350</td><td></td></tr>
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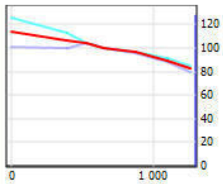

</td><td>Larger floods are associated with higher sediment loads, and with widespread channel instability and reworking of the channel bed and banks. Large floods will thus reset the channel sediments, resulting in overall finer average bed sediment conditions.</td></tr>
<tr><td>
☑ Dry season ave daily vol [D season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y1</th><th>Y2</th></tr>
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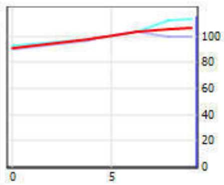

</td><td>The lower the dry season discharge, the more fines that can deposited on the channel bed and thus the smaller the mean bed sediment size will become. The higher the dry season discharge, the more fines that will be removed and the coarser the (now armoured) channel bed will become.</td></tr>
</table>

Table 7.4 Area of secondary channels and backwaters

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Dry season duration [D season]
<table>
<tr><th>Desc</th><th>days</th><th>Y1</th><th>Y2</th></tr>
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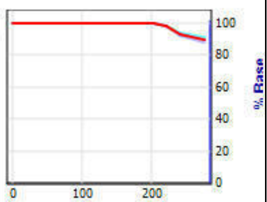

</td><td>During the dry season when sediment levels are low, the active channel bed slowly erodes, increasing capacity and leading to a slow abandonment of secondary channels. The longer the dry season, the more secondary channel abandonment will occur. This process will be exacerbated by reductions in sediment from upstream dams.</td></tr>
<tr><td>
☑ Wet season duration [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>84.000</td><td>0.000</td><td></td></tr>
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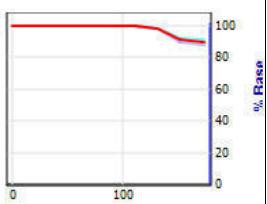

</td><td>longer wet seasons mean a longer period of high flows with relatively lower sediment loads (in this river observed data suggest that the peak sediment loads generally occur early in the wet season, prior to peak discharge). Thus longer wet seasons may mean greater erosion (widening/deepening) in the main channel, causing some loss of secondary channels.</td></tr>
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<table>
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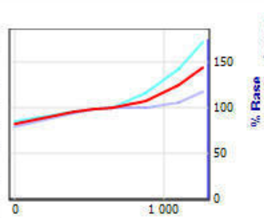

</td><td>Very large floods will overwiden the channel and erode areas for secondary channels to form. Very small/failed floods may not be able to counteract channel narrowing of the low flow season.</td></tr>
<tr><td>
☑ Dry season ave daily vol [D season]
<table>
<tr><th>Desc</th><th>Mm3/d</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-4.000</td><td></td></tr>
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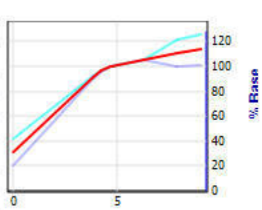


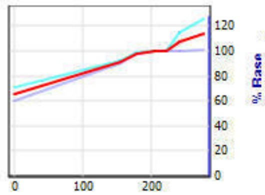
</td><td>The higher the average dry season flows, the more secondary channels will remain active during the low flow season (and thus available for instream biota).</td></tr>
</table>

Table 7.5 Algae

Linked indicator and response curve — Explanation

☑ Dry season duration [D season]

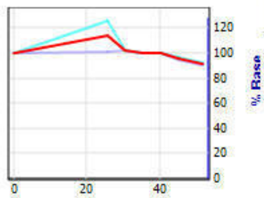
Desc	days	Y1	Y2
Min	0.000	-2.000	
Min Base	154.000	-0.500	
	179.000	-0.100	
Median	204.000	0.000	
	222.000	0.000	
Max Base	240.000	0.500	
Max	276.000	1.000	



Explanation: Longer dry season - more time for algae to become established and temperatures also favourable towards the end of the dry season.

☑ Min 5d dry season Q [D season]

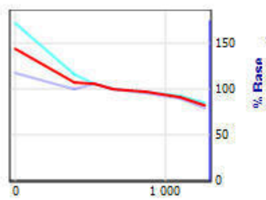
Desc	m3/s	Y1	Y2
Min	0.000	0.000	
Min Base	25.620	1.000	
	30.570	0.100	
Median	35.520	0.000	
	40.260	0.000	
Max Base	45.000	-0.250	
Max	51.750	-0.500	



Explanation: Lower discharge - calmer conditions, better for algae, to a point. At 0 cumecs the river will freeze.

☑ Max 5d wet season Q [F season]

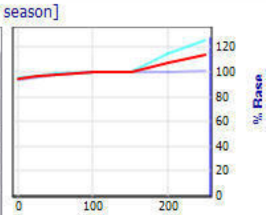
Desc	m3/s	Y1	Y2
Min	0.000	2.000	
Min Base	391.480	0.500	
	522.460	0.200	
Median	653.440	0.000	
	873.940	-0.200	
Max Base	1094.440	-0.500	
Max	1258.606	-1.000	



Explanation: Lower peak flows and warm conditions will favour algae growth. Higher turbidity and currents will adversely affect the population.

☑ Median bed sediment size (armouring) [F season]

Desc	%Base	Y1	Y2
Min	0.000	-0.300	
Min Base	25.000	-0.200	
	50.000	-0.100	
Median	100.000	0.000	
	150.000	0.000	
Max Base	200.000	0.500	
Max	250.000	1.000	



Explanation: The more stable (armoured) the bed, the greater the flows necessary to remove algae.

Table 7.6 EPT (Ephemeroptera, Plecoptera and Trichoptera)

Linked indicator and response curve — Explanation

☑ Dry season duration [D season]

Desc	days	Y1	Y2
Min	0.000	1.000	
Min Base	154.000	0.500	
	179.000	0.000	
Median	204.000	0.000	
	222.000	0.000	
Max Base	240.000	-0.500	
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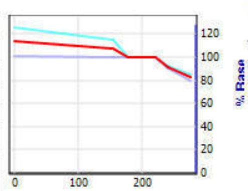
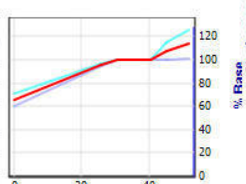


Explanation: Aquatic invertebrates have life-histories that are adapted to wide variations in seasonal flows, but populations are likely to drop slightly if the low-flow period is too long. A longer period of low-flows is also likely to increase the risks of mortality as a result of high water temperature once the seasons change.

☑ Min 5d dry season Q [D season]

Desc	m3/s	Y1	Y2
Min	0.000	-2.000	
Min Base	25.620	-0.250	
	30.570	0.000	
Median	35.520	0.000	
	40.260	0.000	
Max Base	45.000	0.500	
Max	51.750	1.000	

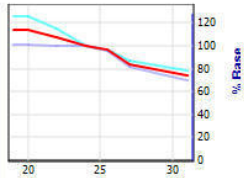


Explanation: With less discharge there is less wetted area.

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Wet season onset [F season]

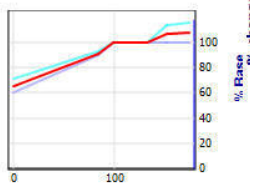
Desc	cal week	Y1	Y2
Min	19.000	1.000	
Min Base	20.000	1.000	
	22.000	0.500	
Median	24.000	0.000	
	25.500	-0.200	
Max Base	27.000	-0.900	
Max	31.050	-1.500	



</td><td>Delayed onset will affect cues for emergence/laying eggs</td></tr>
<tr><td>

☑ Wet season duration [F season]

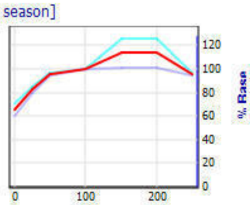
Desc	days	Y1	Y2
Min	0.000	-2.000	
Min Base	84.000	-0.500	
	98.000	0.000	
Median	112.000	0.000	
	131.500	0.000	
Max Base	151.000	0.400	
Max	173.650	0.500	



</td><td>The absence of a wet period will not provide the cues needed for hatching of eggs. Sufficient wet season duration is required to provide time for eggs to mature and hatch.</td></tr>
<tr><td>

☑ Median bed sediment size (armouring) [D season]

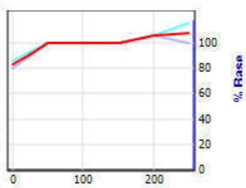
Desc	%Base	Y1	Y2
Min	0.000	-2.000	
Min Base	25.000	-1.000	
	50.000	-0.250	
Median	100.000	0.000	
	150.000	1.000	
Max Base	200.000	1.000	
Max	250.000	-0.250	



</td><td>Fine sediments are difficult to attach to, EPT will do better with a more armoured bed to a point beyond which they will decline again..</td></tr>
<tr><td>

☑ Algae [F season]

Desc	%Base	Y1	Y2
Min	0.000	-1.000	
Min Base	25.000	-0.500	
	50.000	0.000	
Median	100.000	0.000	
	150.000	0.000	
Max Base	200.000	0.200	
Max	250.000	0.500	



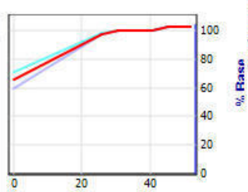
</td><td>EPT eat algae.</td></tr>
</table>

Table 7.7 Snow trout - *S. richardsonii*

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Min 5d dry season Q [D season]

Desc	m3/s	Y1	Y2
Min	0.000	-2.000	
Min Base	25.620	-0.150	
	30.570	0.000	
Median	35.520	0.000	
	40.260	0.000	
Max Base	45.000	0.100	
Max	51.750	0.100	

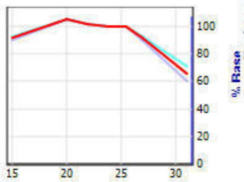


</td><td>Lower flows = lower water levels, low temperatures as a result of lack of buffering. Can tolerate low temperatures and high turbidity. Field surveys in winter recorded temperatures of around 8oC, and air temperatures around 8-9oC.</td></tr>
</table>

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Wet season onset [F season]

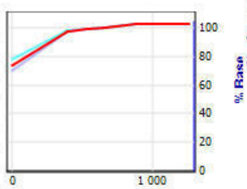
<table>
<tr><th>Desc</th><th>cal week</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>15.000</td><td>-0.500</td><td></td></tr>
<tr><td>Min Base</td><td>20.000</td><td>0.200</td><td></td></tr>
<tr><td></td><td>22.000</td><td>0.050</td><td></td></tr>
<tr><td>Median</td><td>24.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>25.500</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>27.000</td><td>-0.500</td><td></td></tr>
<tr><td>Max</td><td>31.050</td><td>-2.000</td><td></td></tr>
</table>



</td><td>The snow trout breeds during summer season from May to August (Negi 1994). By this time of the year, the fish eggs reach to its final stage of maturity provided the aquatic system provides sufficient food required for proper development of eggs. Once the eggs reach to their final stage of maturity, the fish is ready to spawn under various triggers like the snowmelt, rise in water temperature, comparatively higher turbidity level, swelling of rivers, creation of side channels etc. mainly linked with the monsoon rains and snow melt in the upper reaches of the Himalayan rivers (Rafique and Qureshi 1997). The breeding triggers, however, should coincide with the maturity of eggs in the ovary of fish for successful spawning.
Early onset of the flood season (a month before the median) is predicted to lead to better food availability early in the season, which would help the proper development of eggs leading to improved breeding.
In years when there is a delayed onset of the flood season, it is predicted that the fish would have mature eggs but could miss the necessary triggers for breeding. Eggs could perish within the fish and be reabsorbed. Failure of the flood season would mean that breeding habitats in the side channels do not become available, resulting in the failure of breeding.</td></tr>
<tr><td>

☑ Max 5d wet season Q [F season]

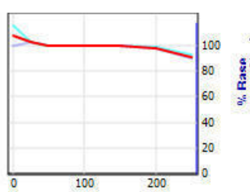
<table>
<tr><th>Desc</th><th>m3/s</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.500</td><td></td></tr>
<tr><td>Min Base</td><td>391.480</td><td>-0.150</td><td></td></tr>
<tr><td></td><td>522.460</td><td>-0.050</td><td></td></tr>
<tr><td>Median</td><td>653.440</td><td>0.000</td><td></td></tr>
<tr><td></td><td>873.940</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>1094.440</td><td>0.100</td><td></td></tr>
<tr><td>Max</td><td>1258.606</td><td>0.100</td><td></td></tr>
</table>



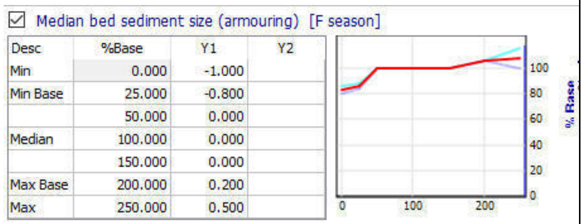
</td><td>Lower flows in the wet season = lower water levels: may result in higher water temperatures as a result of lack of buffering. Can tolerate a range of water temperatures 8°C to 22°C (Sharma, 1989) [optimal temperature 15-16°C]. Field surveys in summer recorded temperatures of around 14-16oC.</td></tr>
<tr><td>

☑ Exposed sand and gravel bars [D season]

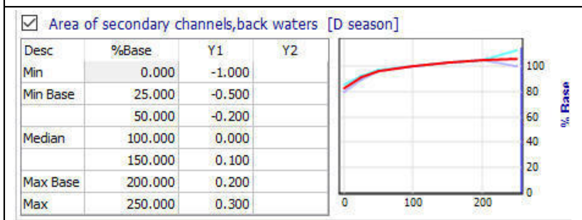
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.100</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-0.100</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-0.500</td><td></td></tr>
</table>



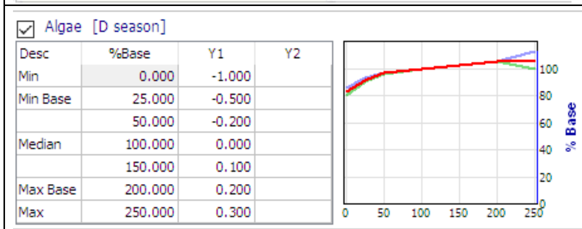
</td><td>Prefer breeding habitat is side streams and back waters with gravel, rocky, cobbly bed. Pools and crevices preferred for wintering. Expanding sand and gravel bars will deteriorate habitat quality (pools and riffles).</td></tr>
</table>

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

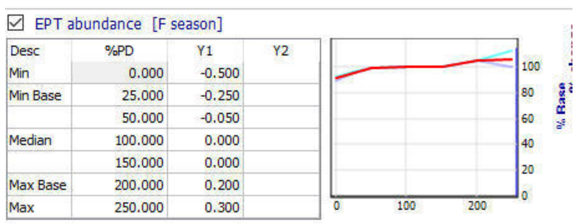
☑ Median bed sediment size (armouring) [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.800</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.500</td><td></td></tr>
</table>
</td><td>The fish favour areas with gravel and algae. Gravel beds, free of fine sediment, provide habitat for attached algae and are the feeding and breeding grounds for snow trout. Armouring would increase the availability of food for this fish, while fine sediment in the bed would reduce the area available for algal growth (Talwar and Jhingran 1991; Raina and Petr 1999).
With decreasing particles size, there would be a higher chance of embeddedness of the spawning areas. The smaller particles fill the interstitial spaces and make it hard for attached algae to grow on the gravely and cobble bed resulting in less fish food production and hence a considerable decrease in fish population.
Accumulation of larger particles in the river bed (armouring) result in a growth of attached algae which is food for the fish. It also becomes the breeding habitat for fish as it prefers the gravely and cobble bed for breeding. Consequently, the armouring of the bed results in a modest increase in fish population.</td></tr>
<tr><td>

☑ Area of secondary channels,back waters [D season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.300</td><td></td></tr>
</table>
</td><td></td></tr>
<tr><td>

☑ Algae [D season]

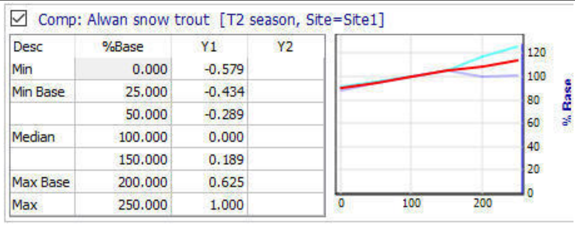
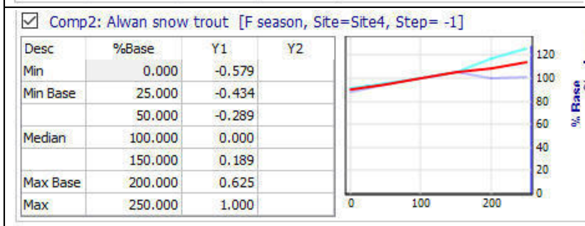
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.300</td><td></td></tr>
</table>
</td><td>Snow trout are omnivorous and feed on algae and aquatic invertebrates (mainly EPT; Raina and Petr 1999). Its mouth is adapted to scraping algae from stones (Rai et. al. undated)).</td></tr>
<tr><td>

☑ EPT abundance [F season]

<table>
<tr><th>Desc</th><th>%PD</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.250</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.050</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.300</td><td></td></tr>
</table>
</td><td>Snow trout are omnivorous and feed on algae and aquatic invertebrates (mainly EPT; Raina and Petr 1999). They are opportunist feeders and their dependence on invertebrates varies depending on the season and stage of maturity. In years with low EPT productivity, the fish would have less invertebrate food and the population would be compromised (Jhingran 1991).
In years with high EPT productivity, all age classes of fish would have better growth and fattening for overwintering and a high fecundity rate, which would lead to overall higher numbers.</td></tr>
<tr><td>

☑ Alwan snow trout [T1 season, Site=Site3, Step= -1]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.737</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.303</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.868</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.640</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.020</td><td></td></tr>
</table>
</td><td>Alsa migrates to Site 2 from downstream</td></tr>
</table>

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
</td><td>Alsa migrates to Site 2 from upstream</td></tr>
<tr><td>
</td><td>Alsa migrates to Site 2 from the Mailun tributary</td></tr>
</table>

8 Scenarios

The Upper Trishuli-1 EFlows assessment comprises consideration of a series of design and operational scenarios for the proposed Upper Trishuli-1 HEP against a **2016 Baseline**.

The scenarios include permutations of:

i. Operating rules – different levels and patterns of EFlows releases
ii. Fish passages – presence/absence of fish passages.

The option of including permutations of sediment maintenance rules were considered but excluded because the EFlows team was assured by the Client that the sediment regime upstream and downstream of Upper Trishuli HEP would remain at baseline levels[1].

Eleven scenarios were selected for assessment as summarised in Table 8.1.

Table 8.1 Scenarios selected for assessment

#	Code	Description	Fish Passage
1	Base-2016	-	-
2	10_MeanM_NoFP	10% of mean baseline monthly flow	No
3	10_MinM_NoFP	10% of minimum baseline monthly flow	No
4	30_MinM_NoFP	30% of minimum baseline monthly flow	No
5	20_MeanM_NoFP	30_MinM, except : 20% of baseline dry season mean monthly flow (10.60 m^3/s) until calendar week 22 (end May) and after week 44 (end October), unless 30_MinM was higher. Aim: Test a higher dry season flow, as Scenarios 2, 3, and 4 all had very low flows and severe effects.	No
6	202_W_noFP	30_MinM, except if 30_MinM was below 202m^3/s (The T1/W threshold) between weeks 26 (end June) and week 40 (beginning October), in which case 202m^3/s was supplied. Aim: To test the ameliorating effects of a less severely shortened wet season	No
7	10_MeanM_FP	10% of mean baseline monthly flow	Yes
8	10_MinM_FP	10% of minimum baseline monthly flow	Yes
9	30_MinM_FP	30% of minimum baseline monthly flow	Yes
10	20_MeanM_FP	30_MinM, except : 20% of baseline dry season mean monthly flow (10.60 m^3/s) until calendar week 22 (end May) and after week 44 (end October), unless 30_MinM was higher. Aim: Test a higher dry season flow, as Scenarios 2, 3, and 4 all had very low flows and severe effects.	Yes
11	202_W_FP	30_MinM, except if 30_MinM was below 202m^3/s (The T1/W threshold) between weeks 26 (end June) and week 40 (beginning October), in which case 202m^3/s was supplied. Aim: To test the ameliorating effects of a less severely shortened wet season	Yes

[1] This is an important assumption as it is rare that in-channel weirs have no effect on the downstream movement of suspended or bedload sediments, and changes in sediment supply can be a major cause of impact to rivers downstream of dams and weirs.

8.1 Assumption for barriers to fish

The influence of the Upper Trishuli-1 HEP weir and reservoir on Asla populations at the various sites is partially attributable to the barrier created to the movement of fish between breeding and feeding areas, or between the main steam and tributaries. To account for this influence, the DRIFT DSS considered the influence of Upper Trishuli-1 HEP on the movement of Asla snow trout between the EFlows sites.

Within the DRIFT DSS, the barrier effect of water resource developments is modelled through specifying percentage reductions (or increases) in the "connectivity" between one site and another. Connectivity effects are specified per indicator. For the purposes of illustrating *potential* impacts of fish passage the following applied:

- With UT weir in place and <u>no fish passage</u>: 100% reduction in both upstream and downstream connectivity for *S. richardsonii* between Site1 and Site2.
- With UT weir in place <u>with a fish passage</u>: 50% reduction in both upstream and downstream connectivity for *S. richardsonii* between Site1 and Site2.

The change in connectivity that was modelled in DRIFT does not imply that this level is achievable.

The impact of the barrier on fish is dictated by a combination of migration success and dependence on migration. For instance, a population of fish may depend on getting past a barrier in order to access spawning / breeding grounds, and there may be no other location where the fish breed: this population would be highly dependent on migration.

9 Results of scenario analyses

For each scenario, the predicted changes in the river ecosystem are evaluated per site as:

1. estimated mean percentage change from baseline in the abundance, area or concentration of key indicators, and;
2. a time-series of abundance, area or concentration of key indicators under the flow regime resulting from each scenario.

Site 1 is not affected by flow changes as a result of Upper Trishuli-1 HEP, but depending on the scenarios, they may be affected by the barrier effect of the Upper Trishuli-1 Weir. Similarly Sites 3 and 4 (on the Mailun Tributary) are not affected by flow changes as a result of Upper Trishuli-1 HEP, but may be affected by the barrier created by the weir. Site 2 is expected to be affected by flow changes as a result of Upper Trishuli-1 HEP, plus by the barrier created by the weir.

9.1 Site 1[2]

9.1.1 Characteristics of the flow regime of each scenario at Site 1

The main characteristics (median values) of the flow regimes associated with each of the scenarios are summarised in Table 9.1.

If constructed, Upper Trishuli-1 HEP would not affect flows or sediment supply at Site 1. Thus, all the scenarios have the same flow regime at Site 1.

Table 9.1 Characteristics of the baseline flow regime at Site 1. Median values are given for the flow indicators.

Flow indicators	Units	Baseline
Mean annual runoff	m^3/s	177.33
Dry season onset	week	44.00
Dry season duration	days	204.00
Min 5d dry season Q	m^3/s	35.52
Wet season onset	week	24.00
Wet season duration	days	112.00
Max 5d wet season Q	m^3/s	653.44
Flood volume	MCM	3947.17
Dry season ave daily vol	MCM	4.68
T1 ave daily vol	MCM	12.88
Wet season ave daily vol	MCM	36.06
T2 ave daily vol	MCM	11.74
T2 recession slope	-	-3.52

[2] Site 1 is upstream of dam/weir site

9.1.2 *Mean percentage changes*

The mean percentage changes (relative to Baseline) for the indicators for each scenario at Site 1 are given in Table 9.2.

Table 9.2 Site 1: The mean percentage changes (relative to Baseline, which equals 100%) for the indicators for each scenario. Change representing an improvement in condition relative to baseline is marked in green[3]. Change representing a decline in condition relative to baseline is marked as follows: Orange = change >40-70%; red = change >70%.

	Indicators	10_MeanM_NoFP	10_MinM_NoFP	30_MinM_NoFP	20_MeanM_NoFP	202_W-NoFP	10_MeanM_FP	10_MinM_FP	30_MinM_FP	20_MeanM_FP	202_W_FP
Geo-morphology	Bedload inflows	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Suspended Sediment inflow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Suspended sediment load	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
	Exposed sand and gravel bars	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Exposed cobble and boulder bars	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
	Median bed sediment size (armouring)	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
	Area of secondary channels and back waters	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Algae	Algae	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Macro-invertebrates	EPT abundance	-3.9	-3.9	-3.9	-3.9	-3.9	-3.9	-3.9	-3.9	-3.9	-3.9
Fish	Snow trout: *S. richardsonii*	-92.0	-92.0	-92.0	-92.0	-92.0	-49.8	-49.8	-49.8	-49.7	-49.7

The results indicate that the fate of the snow trout population upstream of the Upper Trishuli River is largely dependent on the efficacy of the fish passage provided in facilitating movement of these fish from their over-wintering areas downstream of Upper Trishuli-1 HEP to their breeding areas upstream. Provided this passage will allow 50% of the mature migrating fish up past the weir and through the reservoir, and adults and juveniles back down through the reservoir and down past the weir, then the Asla are expected to survive upstream of Upper Trishuli-1 HEP.[4]

9.1.3 *Overall Integrity*

The Overall Integrity for each of the scenarios at Site 1 is illustrated in Figure 9.1. Given that the trout would survive at Site 1, the impact on overall integrity is expected to be minor provided there is a fish passage that allows for 50% of both upstream and downstream migrants to pass Upper Trishuli HEP.

3 These predictions report the last 10 years of the hydrological record used as the basis for scenarios.

4 But see comment on rainbow trout in Section 11.1

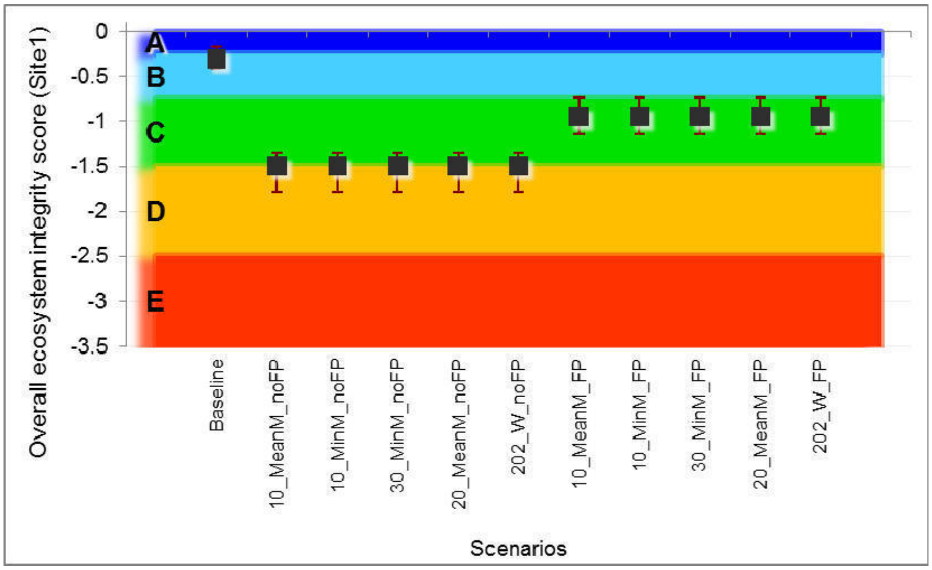


Figure 9.1 Overall ecosystem integrity scores for the scenarios at Site 1.

9.2 Site 2[5]

9.2.1 Characteristics of the flow regime of each scenario at Site 2

The main characteristics (median values) of the flow regimes associated with each of the scenarios are summarised in Table 9.3.

Table 9.3 Characteristics of the baseline and scenario flow regimes at Site 2. Median values are given for the flow indicators.

	Units	Baseline	10_MeanM	10_MinM	30_MinM	20_MeanM	202_W
Mean annual runoff	m^3/s	177.33	116.87	116.22	117.58	119.73	119.46
Dry season onset	week	44.00	41.00	41.00	41.00	41.00	41.00
Dry season duration	days	204.00	243.00	243.00	243.00	243.00	243.00
Min 5d dry season Q	m^3/s	35.52	3.88	3.88	3.88	10.60	3.88
Wet season onset	week	24.00	25.00	25.00	25.00	25.00	25.00
Wet season duration	days	112.00	91.00	91.00	91.00	91.00	99.00
Max 5d wet season Q	m^3/s	653.44	577.44	577.44	577.44	577.44	577.44
Flood volume	MCM	3947.17	3012.46	3012.46	3012.46	3012.46	3147.06
Dry season ave daily vol	MCM	4.68	1.29	1.21	1.39	1.68	1.37
T1 ave daily vol	MCM	12.88	15.01	15.01	15.01	15.01	15.53
Wet season ave daily vol	MCM	36.06	33.27	33.27	33.27	33.27	31.50
T2 ave daily vol	MCM	11.74	11.83	11.83	11.83	11.83	11.53
T2 recession slope	-	-3.52	-6.00	-6.00	-6.00	-6.00	-9.51

[5] Site 2 is in the dewatered zone

9.2.2 Mean percentage changes

The mean percentage changes (relative to Baseline) for the indicators for each scenario at Site 2 are given in Table 9.4.

The values provided in Table 9.4 are for the year round population of *S. richardsonii*, which means that they are fairly severe. This is almost wholly due to the low dry season releases for this 12 km reach of river, which negatively affects habitat availability and food supply. As already reported (Section 4), there was some suggestion at the outset of this study that the trout would have migrated downstream from this section at the onset of winter to avoid the cold temperatures, but that they were in fact recorded here in this and other studies. It is, however, likely that, with the decrease in winter low flows as a result of Upper Trishuli-1 HEP, the snow trout will in fact vacate this reach in winter; i.e. migrate downstream for the winter months, provided such migration is possible, i.e., is not blocked by other HEPs.

Table 9.4 Site 2: The mean percentage changes (relative to Baseline, which equals 100%) for the indicators for each scenario – assuming *S. richardsonii* is resident at Site 2 year-round. Change representing an improvement in condition relative to baseline is marked in green6. Change representing a decline in condition relative to baseline is marked as follows: Orange = change >40-70%; red = change >70%**.**

Indicators		10_MeanM_NoFP	10_MinM_NoFP	30_MinM_NoFP	20_MeanM_NoFP	202_W-NoFP	10_MeanM_FP	10_MinM_FP	30_MinM_FP	20_MeanM_FP	202_W_FP
Geo-morphology	Bedload inflows	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Suspended Sediment inflow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Suspended sediment load	-16.2	-16.2	-16.2	-16.2	-9.6	-16.2	-16.2	-16.2	-16.2	-9.6
	Exposed sand and gravel bars	8.4	8.7	8.2	7.5	7.5	8.4	8.7	8.2	7.5	7.5
	Exposed cobble and boulder bars	19.1	19.4	18.8	18.0	15.5	19.1	19.4	18.8	18.0	15.5
	Median bed sediment size (armouring)	-10.0	-10.3	-9.7	-8.8	-9.8	-10.0	-10.3	-9.7	-8.8	-9.8
	Area of secondary channels and back waters	-77.0	-79.4	-74.9	-68.7	-75.4	-77.0	-79.4	-74.9	-68.7	-75.4
Algae	Algae	8.1	8.0	8.1	10.1	7.9	8.1	8.0	8.1	10.1	7.9
Macro-invertebrates	EPT abundance	-49.1	-49.1	-49.1	-41.8	-44.7	-49.1	-49.1	-49.1	-41.8	-44.7
Fish	Snow trout: *S. richardsonii*	-85.2	-86.0	-84.6	-68.3	-83.9	-82.0	-82.8	-81.4	-64.3	-80.7

A key factor for Site 2 is that the Upper Trishuli-1 HEP, provided it is operated as indicated by the scenarios, is not expected to impinge of the onset of the wet season (~1 week delay expected; see Table 9.3). This means that it is not expected to seriously disrupt the migration cues for the snow trout, which, as far as is known, are a combination of flow, sediment and

[6] These predictions report the last 10 years of the hydrological record used as the basis for scenarios.

temperature cues (e.g., Jhingran 1991; Welcomme 1985; Sunder 1997). Thus, if fish do migrate out of the Site 2 reach in winter, they should migrate back up in the spring.

Other important findings are:

- increasing the dry season low flow release from Upper Trishuli-1 HEP (i.e., 20_MeanM_FP) will result in a ~14% improvement in the outcome of the snow trout at Site 2;
- reducing the impact on onset and duration of dry season, through provision of T1/W and W/T2 at 202m^3/s seasonal cusps (i.e., 202_W_FP) improves the predicted outcome for the snow trout by ~7%.

If the assessment is run assuming that, under baseline conditions, the snow trout migrate away from Site 2 in the cold winter months, then the predicted outcomes are those shown in Table 9.5.

Table 9.5 Site 2: The mean percentage changes assuming *S. richardsonii* migrates downstream and away from Site 2 in the winter

Indicator		10_MeanM_NoFP	10_MinM_NoFP	30_MinM_NoFP	20_MeanM_NoFP	202_W-NoFP	10_MeanM_FP	10_MinM_FP	30_MinM_FP	20_MeanM_FP	202_W_FP
Fish	Snow trout: *S. richardsonii*	-38.1	-39.3	-37.1	-33.6	-36.3	-34.1	-35.3	-33.1	-29.6	-32.4

9.2.3 Overall Integrity

The Overall Integrity for each of the scenarios at Site 2 is illustrated in Figure 9.2. As is the case for Table 9.4, the integrity reflects the fact that the overwintering population of *S. richardsonii* is expected to be impacted by (mainly) the low flow releases from Upper Trishuli-1 HEP.

The summer integrity of this reach would be better (Figure 9.3). That said, the results of the field work done in this study indicate that the snow trout DO reside at Site 2 all year round. However, long term field measurements should be carried out to justify the results obtained from the field study since different literatures mention that S. richardsonii is a mid-distant migratory fish species.

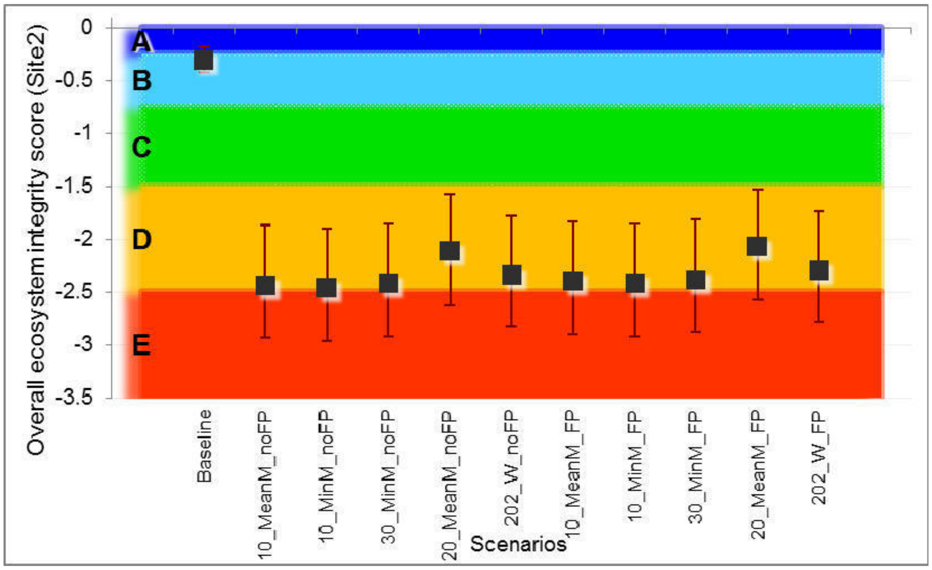


Figure 9.2 Overall ecosystem integrity scores for the scenarios at Site 2 – assuming *S. richardsonii* is a year-round resident.

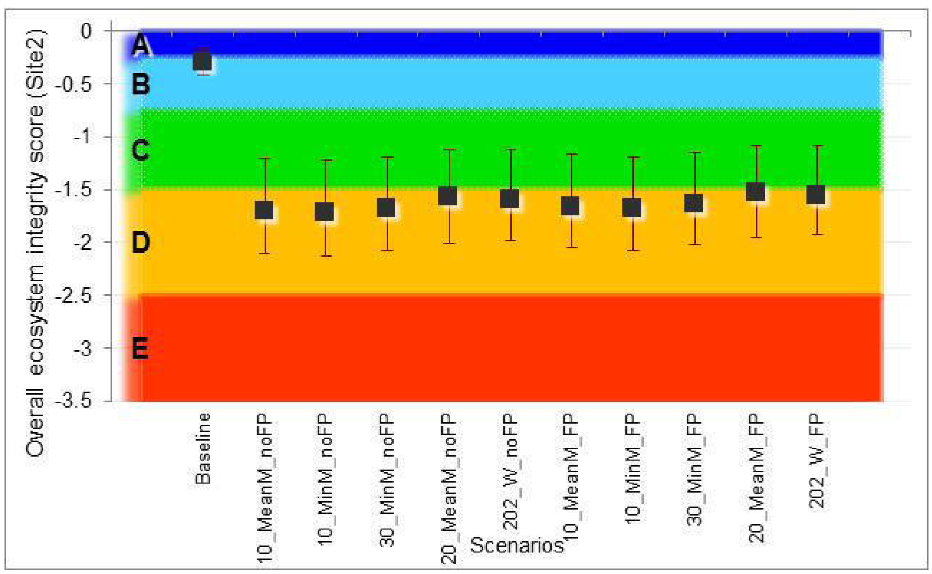


Figure 9.3 Overall ecosystem integrity scores for the scenarios at Site 2 – assuming *S. richardsonii* is a summer resident.

9.3 Site 3[7]

9.3.1 Characteristics of the flow regime of each scenario at Site 3

The main characteristics (median values) of the flow regimes associated with each of the scenarios are summarised in Table 9.6.

Table 9.6 Characteristics of the baseline flow regime at Site 3. Median values are given for the flow indicators.

Flow indicators	Units	Baseline
Mean annual runoff	m^3/s	179.81
Dry season onset	week	44.00
Dry season duration	days	204.00
Min 5d dry season Q	m3/s	36.02
Wet season onset	week	24.00
Wet season duration	days	112.00
Max 5d wet season Q	m3/s	662.58
Flood volume	MCM	4002.38
Dry season ave daily vol	MCM	4.74
T1 ave daily vol	MCM	13.06
Wet season ave daily vol	MCM	36.57
T2 ave daily vol	MCM	11.90
T2 recession slope	-	-3.57

9.3.2 Mean percentage changes

The mean percentage changes (relative to Baseline) for the indicators for each scenario at Site 3 are given in Table 9.7.

The predicted impacts of Upper Trishuli-1 HEP are small at Site 3, and are mainly related to the barrier effects of Upper Trishuli weir, which are minor at the downstream site.

9.3.3 Overall Integrity

The Overall Integrity for each of the scenarios at Site 3 is illustrated in Figure 9.4. The change in integrity with Upper Trishuli-1 HEP in place is related to that slight impact that the barrier is expected to have on downstream populations. This is expected to be relatively minor because there is breeding habitat downstream of Upper Trishuli-1 HEP.

[7] Site 3 is immediately Downstream of the Powerhouse site

Table 9.7 Site 3: The mean percentage changes (relative to Baseline, which equals 100%) for the indicators for each scenario. Change representing an improvement in condition relative to baseline is marked in green[8]. Change representing a decline in condition relative to baseline is marked as follows: Orange = change >40-70%; red = change >70%.

Indicators		10_MeanM_NoFP	10_MinM_NoFP	30_MinM_NoFP	20_MeanM_NoFP	202_W-NoFP	10_MeanM_FP	10_MinM_FP	30_MinM_FP	20_MeanM_FP	202_W_FL
Geo-morphology	Bedload inflows	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Suspended Sediment inflow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Suspended sediment load	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
	Exposed sand and gravel bars	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Exposed cobble and boulder bars	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
	Median bed sediment size (armouring)	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
	Area of secondary channels and back waters	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Algae	Algae	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Macro-invertebrates	EPT abundance	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
Fish	Snow trout: *S. richardsonii*	-18.8	-18.8	-18.8	-18.6	-18.8	-13.9	-13.9	-13.9	-13.6	-13.9

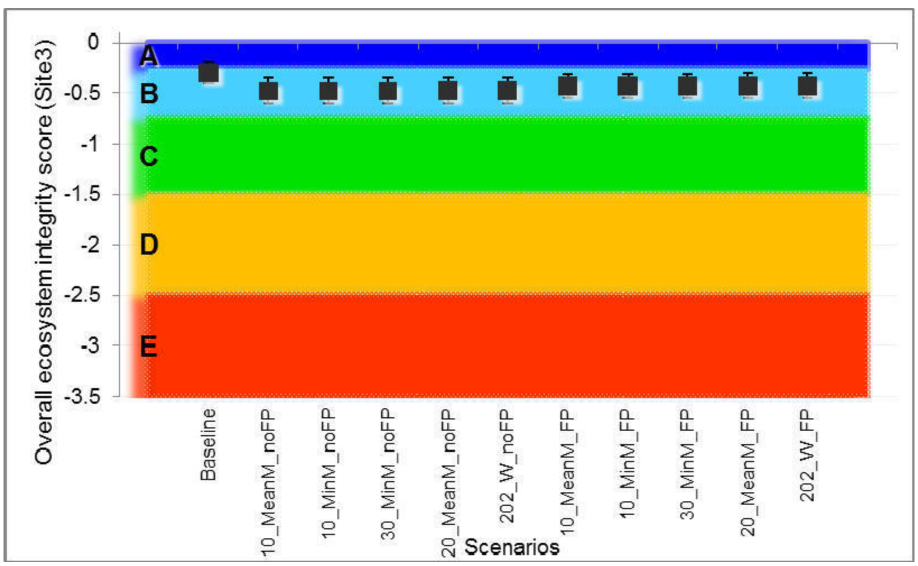


Figure 9.4 Overall ecosystem integrity scores for the scenarios at Site 3.

[8] These predictions report the last 10 years of the hydrological record used as the basis for scenarios.

10 Energy production and ecosystem Integrity at Site 2

The effect of different levels of EFlows releases on energy production was evaluated for different scenarios with the assumption that a fish passage will be constructed. The scenarios selected for comparison of energy production are: 10_MeanM_FP, 10_MinM_FP, 30_MinM_FP, 20_MeanM_FP and 202_W_FP. The descriptions of these scenarios are given in Table 8.1. The calculated energy production under each is shown in Table 10.1.

Table 10.1 Energy Production under different EFlows scenarios

Eflows Scenarios	Energy Production (GWh)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	% Change
10_MeanM_FP	84.5	68.9	74.8	91.0	133.6	153.8	162.7	162.8	157.5	161.3	137.8	105.0	1493.6	0.0
10_MinM_FP	85.6	69.0	74.8	93.1	139.9	156.7	162.8	162.8	157.5	162.4	142.9	108.3	1515.6	1.5
30_MinM_FP	84.5	68.9	74.8	77.4	129.5	153.8	162.7	162.8	157.5	161.3	137.8	105.0	1475.9	-1.2
20_MeanM_FP	71.2	55.8	60.4	77.4	129.5	153.8	162.7	162.8	157.5	161.3	134.1	94.0	1420.4	-4.9
202_W_FP	84.5	68.9	74.8	77.4	129.5	131.0	154.1	161.5	136.2	161.3	137.8	105.0	1422.1	-4.8

The headloss data were not available from the Client, and a fixed amount of headloss for different flow conditions, i.e., 3% of the gross head, was assumed. This is not true in reality because headloss varies with the change in discharge passing through different project components from headworks to the powerhouse, but is sufficiently correct to allow for comparison between scenarios.

Table 10.1 shows that the 10_MinM_FP scenario (legally binding criteria) allows for generation of about 1.5% of annual energy than the 10_MeanM_FP scenario (the Client's commitment in the EIA report). Similarly, relative to 10_MinM_FP, 30_MinM_FP 20_MeanM_FP and 202_W_FP scenarios result in about 1.2%, 4.9% and 4.1% less annual energy, respectively.

Energy production decreases in the order of increasing EFlow releases (Figure 10.1 and Figure 10.2). Figure 10.2 shows the relationship between energy production and overall (median of the sites) ecosystem Integrity for the five scenarios.

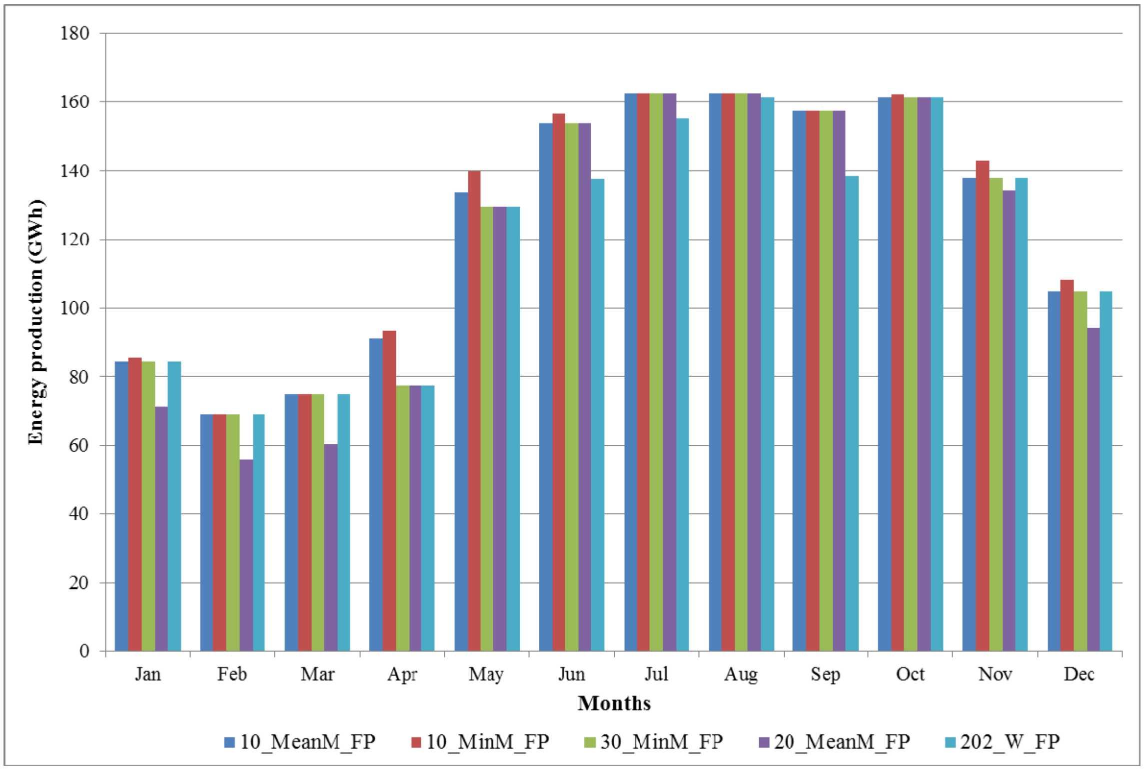


Figure 10.1 Energy production under different EFlows scenarios

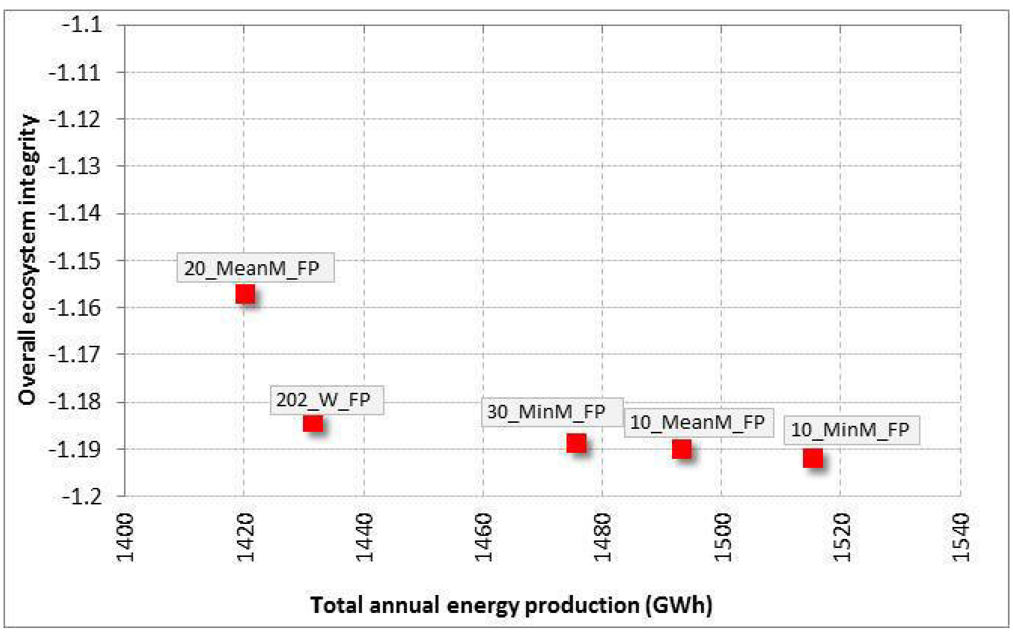


Figure 10.2 Ecosystem Integrity (median of the Sites) vs energy production

11 Additional Considerations

11.1 The effect of rainbow trout

It is important to highlight that the potential impacts of the exotic rainbow trout on snow trout have not been considered in this study, and could be severe. Rainbow trout are known to favour cold clear waters, and prey on snow trout. It is possible that the conditions created by Upper Trishuli-1 HEP and other HEPs in the Trishuli River will favour rainbow trout that escape from aquaculture farms in the area to the detriment of snow trout.

11.2 The effect of downstream and tributary HEPs

The results presented here assume that *S. richardsonii* will be able to migrate down the Trishuli River downstream of Upper Trishuli-1 HEP, and upstream in the tributary between Sites 2 and 3 (i.e., the Mailun River). If this is not the case, then the outcome for the trout will be significantly worse. A study on the cumulative impacts of all the HEPs planned for the Trishuli watershed is currently being undertaken by NWEDC and collaborators.

11.3 Contributions from Tributaries

A recent study on discharge measurement of tributaries of the UT-1 HEP in the dewatered zone conducted by S.A.N. Engineering Solutions Pvt. Ltd. (unpublished report) indicates that tributaries contribute to the main river flow in the dewatered zone. The contribution is, however, small relative to the main river flow and it is not considered during the EFlows modelling. The Fisheries Migration Research Field Visit Report by Halvard Kassa (March 2015) reveals low fish densities in the main river and high in the tributaries. The report concluded *"The data sampled in February/March give indications of a relatively small fish population in the main river with low fish densities compared to high fish densities in the tributaries. More data from other parts of the year are needed. Data so far are weak."* Therefore, flow available in the tributaries during the lean season (March, April and May) is likely to favour fish migration and breeding and the severe impacts on *S. richardsonii* are expected to be reduced with increase in EFlows of the main river though to a lesser extent.

11.4 Fish Passage

The fish passage modelled here allowed for an approximately 50% success rate. A fish passage in Nepal (Khimti Khola), which has particularly favourable design features, has achieved a higher success rate than this (Halvard Kaasa, unpublished presentation). Some of the findings of the Khimti Khola Fish Passage are also reported in the Environmental Monitoring Report published by Himal Power Limited in November, 2006. A fish passage for UT-1 is currently being designed by Halvard Kaasa, who is following good international practice.

11.5 *S. richardsonii* migration patterns

It was anticipated that the snow trout would not be resident immediately downstream of Upper Trishuli-1 HEP in the winter months, and therefore would not be impacted by the low flow releases from the weir, but this could not be proven in the time available for the study. It is, however, highly likely that the trout would migrate away from this reach in winter once Upper Trishuli-1 HEP is in place, particularly if low flow releases remain at design levels. More research is needed on the migration pattern of *S. richardsonii* in the Upper Trishuli River, particularly for the larger fish.

12 Conclusions and Next Steps

As represented by the indicators used in this study, Upper Trishuli-1 HEP is likely to affect the aquatic ecology of the Trishuli River. However, provided adequate provision is made for successful upstream and downstream passage of snow trout past the HEP, then the bulk of its impact should be within the 12-km dewatered stretch of the river.

Five EFlows scenarios were evaluated at three EFlows sites ([1] upstream of dam site; [2] downstream of the powerhouse site and; [3] in the dewatered section of the river). Upstream and downstream of UT-1, the ecological integrity and fish populations will not be impacted much, and the main impacts will be on the overwintering fish populations in the 12-km dewatered stretch. Inclusion of an effective fish passage will assist in maintaining the *S. richardsonii* migration within the watershed and ensure solid populations upstream and downstream of the project area.

The results of the EFlows assessment not surprisingly conclude that the best EFlows scenario for the *S. richardsonii* is the release of more water during the winter (low flow) months. However, power generation will be negatively impacted with the release of more water. Given the conditions of the Power Development Agreement between NWEDC and the Government of Nepal, and the financial situation of the project, it is highly unlikely that the project will be financially viable with this level of power loss. Furthermore, NWEDC has committed to a higher EFlows (10 % of baseline mean monthly flow) than is legally required by the Hydropower Development Policy, 2001. NWEDC has also exhibited commitment to biodiversity management for UT-1 through extensive baseline data collection, inclusion of a fish ladder that will meet international standards, a cumulative impacts assessment and this EFlows assessment.

Thus, the impacts on *S. richardsonii* within the 12 km dewatered zone will be mitigated by ensuring that migration is relatively unimpeded and that fish populations persist in the area. Apart from increased EFlows, the mitigation measures could include provision of a functional and efficient fish passage, fish hatcheries, and effective monitoring mechanism and adaptive management. Once decided upon, the agreed mitigation measures will be detailed in an Environmental Flow Management Plan.

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Appendix A. **OVERVIEW OF DRIFT**

This appendix is a generic overview of DRIFT and as such may use examples from areas other than the Upper Trishuli River. The Upper Trishuli EFlows assessment was completed using Drift2-v2.97.exe.

DRIFT is a process and data-management DSS, allowing data and knowledge to be used to their best advantage in a structured way. Within DRIFT, discipline specialists use their own discipline-specific methods to derive the links between river flow and river condition. The central rationale of DRIFT is that different aspects of the flow or sediment regime of a river elicit different responses from the riverine ecosystem. Thus, removal of part or all of a particular element of the flow or sediment regime will affect the riverine ecosystem differently than will removal of some other element.

In DRIFT, the long-term daily-flow time-series is partitioned into parts of the flow regime that are thought to play different roles in sculpting and maintaining the river ecosystem, such as the onset of important flow seasons, which may affect breeding cycles, or the magnitude of the annual flood, which may inundate a floodplain. This makes it easier for ecologists to predict how changes in the flow regime could affect the ecosystem. The 'parts' of the flow regime used in DRIFT are called flow indicators. The indicators used for the Upper Trishuli River are presented in Section 5.

The variability of the flow regime in timing and magnitude, both in its natural state and in any future scenario, is captured automatically through algorithms within the hydrological module of the DSS that identify the nature of the flow indicators year-by-year. Thus, the 47 annual values of each flow indicator are provided for the 47 years of flow record. This means the specialists can consider a response to a condition for a particular time-step rather than thinking of an averaged response over several years. They can also use data from a particular year or season to calibrate time-series responses.

The study process was structured as follows:

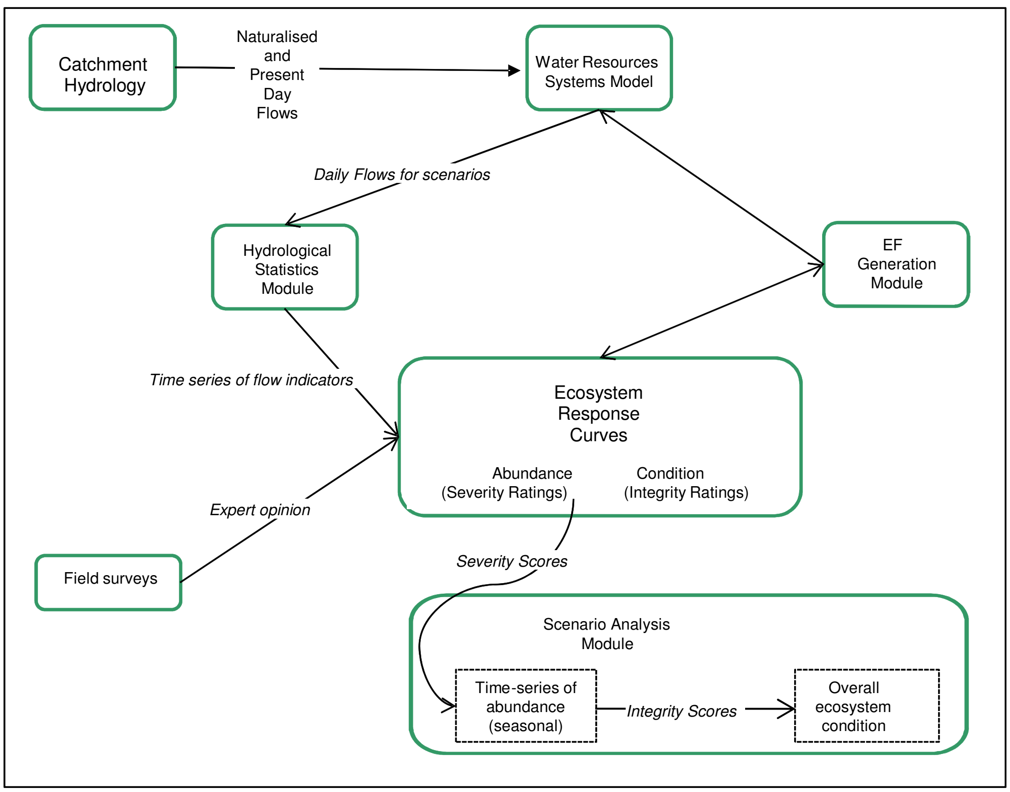
1. The study focused on five focus areas in the Upper Trishuli River (Section 1.2.1).
2. The flow changes were converted to ecologically-relevant summary statistics that highlighted:
    i. Changes in magnitude.
    ii. Changes in duration.
    iii. Changes in timing of seasons (e.g., delayed onset of wet season).
    iv. Changes within day ranges in discharge (i.e., for peaking power releases).
3. Specialists provided opinion on the consequences of these changes in the form of Response Curves. The disciplines represented were:
    i. Geomorphology
    ii. Macro invertebrates
    iii. Fish

Each specialist provided a list of ecosystem attributes that they believe could change with flow change. These are called ecosystem indicators.

4. The database was used to evaluate changes in these indicators for each scenario listed in Section 8.
5. The outputs of the DRIFT database are written up in Section 9.

The basic sequence of activities in the DRIFT DSS can be summarised as follows (Appendix Figure 1):

1. Collect data for the study at the river.
2. Augment with expert knowledge for similar river systems and a global understanding of river functioning.
3. Model current catchment hydrology and scenarios of future changes.
4. Calculate annual flow indicator time-series for all scenarios.
5. Construct relationships for the expected response of individual ecosystem indicators to changes in aspects of the flow regime (Response Curves). The Response Curves show the extent of change (i.e. severity of change – on a scale of 0 (no change) to 5 (very high change)) from baseline that would be expected from an ecosystem indicator in response to specific changes in flow.
6. Use Response Curves to predict time-series of abundance changes in each ecosystem indicator as a response to flow and consequent other changes.
7. Calculate Integrity for each indicator by assigning a direction of change, i.e., whether an increase in abundance will be expected to move the indicator away from the natural ecosystem condition or the opposite, and from this calculate discipline and site level Integrity.



Appendix Figure 1 Flow chart of DRIFT process

A.1. RESPONSE CURVES[9]

Response Curves depict the relationship between a biophysical indicator and a driving variable (e.g., flow). In this EFlows assessment, Response Curves linked an indicator to any other

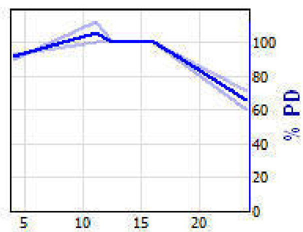
[9] The bulk of this section is taken from Joubert *et al*., 2009.

indicator deemed to be driving change. The aim is not try to capture every conceivable link, but rather to restrict the linkages to those that are most meaningful and can be used to predict the bulk of the likely responses to a change in the flow or sediment regimes of the river.

A Response Curve for the relationship between relative fish (e.g., Alwan Snow Trout) abundance (given as a severity rating – see Section A.2 for an explanation of the scoring system used) and a flow category, in this case, onset of the wet season, is shown in Appendix Figure 2. In this figure, an early or late start to the wet season would lead to decreased abundance.

☑ Wet season onset [F season]

Desc	cal week	Y
Min	4.00	-0.500
MinPD	11.00	0.250
	12.50	0.000
Median	14.00	0.000
	16.00	0.000
Max PD	18.00	-0.500
Max	24.00	-2.000



Appendix Figure 2 Example of a Response Curve – in this case of the relationship between the calendar week when the wet season begins and the abundance of Alwan Snow Trout.

The units on the x-axis depend on the driving variable under consideration. For instance, in the case of wet season onset (Appendix Figure 2), these are weeks of the year.

The y-axis may refer to abundance as in Appendix Figure 2, but also to other measures such as concentration or area, depending on the indicator. Response curves are constructed using severity ratings (Section A.2).

The number of Response Curves constructed for an EFlows assessment depends on the level of detail at which a flow assessment is done. In the NJHEP assessment, for example, the specialists collectively completed 57 Response Curves for Site 2. These were used to evaluate scenarios by taking the value of the flow indicator for any one scenario and reading off the resultant values for the biophysical indicators from their respective Response Curves. Once this had been done the database combined these values to predict the overall change in each biophysical indicator and in the overall ecosystem under each scenario.

A.1.1. Construction of the Response Curves

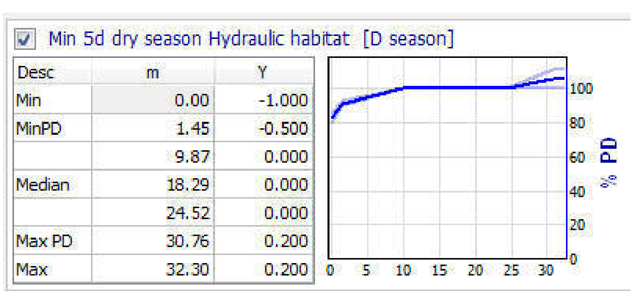
The Response Curves used in this project were constructed based on response curves constructed for the Neelum River, Pakistan. The Response Curves and explanations for their shape are contained in the DRIFT DSS, and in Section 7.

A.1.2. Response Curves and cumulative change

The time-series approach means that the Response Curves are used to predict the likely seasonal change in an ecosystem indicator in response to the flow/sediment conditions experienced in that, or possibly preceding, seasons. For instance, the kind of questions and discussion typically addressed to facilitate setting the Response Curves the effect of changes in dry season discharge on Alwan Snow Trout are:

- "If the dry season discharge declines from baseline values, what will be the consequences for the abundance of Alwan Snow Trout?"
    - Do Alwan Snow Trout use the main river in the dry season?
    - Do Alwan Snow Trout abundances change noticeably over the climatic range covered in the baseline, i.e., are they noticeably more abundant in wet years than in dry years, or vice versa?
    - What kinds of habitat do adult Alwan Snow Trout use in the main river?
    - Do Alwan Snow Trout breed in the dry season?
    - Do they breed in the main river or in the tributaries?
    - Where do Alwan Snow Trout lay their eggs?
    - What sorts of habitat do fry, fingerlings and juvenile trout use in the main river?
    - At what discharge(s) does the favored habitat(s) disappear?
    - What is the consequence of these habitats not being available for one season?
    - If discharge reaches zero for one season, are there pools that the trout will be able to survive in?
    - Can the Alwan Snow Trout survive for a dry season in pools?
    - Is water temperature a concern, i.e., would the river freezing be an issue for Alwan Snow Trout if discharge decreased?
    - What do Alwan Snow Trout adults/juveniles/fingerlings/fry eat?
    - How will the food base be affected by changes in dry season low flows?
    - Etc.

Often, a species such as Alwan Snow Trout will be expected to survive even an extremely-dry dry season, with possibly only minor changes (5-10%) in overall abundance, resulting in a Response Curve similar to that shown in Appendix Figure 3, which predicts a 20-40% seasonal decline in trout abundance if dry season flows drop to zero, even though the lowest 5-day minimum ever recorded at the Line of Control under baseline is 11.78 m^3/s. If, however, the flows drop to this level in the dry season year after year, then the cumulative effect on trout populations is likely to be far greater. The time-series enable the DSS to capture this cumulative effect.



Appendix Figure 3 Response curve for Alwan Snow Trout response to changes in minimum 5-day dry season discharge.

A.2. SCORING SYSTEM

Into the foreseeable future, predictions of river change will be based on limited knowledge. Most river scientists, particularly when using sparse data, are thus reluctant to quantify predictions: it is relatively easy to predict the nature and direction of ecosystem change, but more difficult to predict its timing and intensity. To calculate the implications of loss of resources to subsistence and other users in order to facilitate discussion and trade-offs, it is nevertheless necessary to quantify these predictions as accurately as possible.

To aid this, two types of information are generated for each biophysical indicator, *viz.*:

- Severity ratings, which describe increase/decreases for an indicator in response to changes in the flow indicators, and;
- Integrity ratings, which indicate whether the predicted change is a move towards or away from the natural ecosystem condition, i.e., how the change influences overall ecosystem condition.

The severity ratings are used to construct the Response Curves. The Integrity ratings are used to predict changes in overall ecosystem condition/health.

A.2.1. Severity ratings

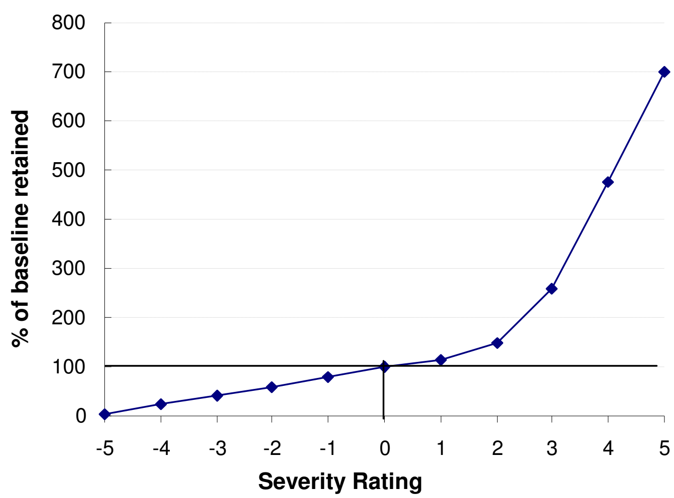
The severity ratings are on a continuous scale from -5 (large reduction) to +5 (very large change; Brown *et al*., 2008; Appendix Table 1), where the + or – denotes an increase or decrease in abundance or extent. These ratings are converted to percentages using the relationships provided in Appendix Table 1. The scale accommodates uncertainty, as each rating encompasses a range of percentages; however, greater uncertainty can also be expressed through providing a range of severity ratings (i.e. a range of ranges) for any one predicted change (after King *et al.*, 2003).

Appendix Table 1 DRIFT severity ratings and their associated abundances and losses – a negative score means a loss in abundance relative to baseline, a positive means a gain.

Severity rating	Severity	% abundance change
5	Critically severe	501% gain to ∞ up to pest proportions
4	Severe	251-500% gain
3	Moderate	68-250% gain
2	Low	26-67% gain
1	Negligible	1-25% gain
0	None	no change
-1	Negligible	80-100% retained
-2	Low	60-79% retained
-3	Moderate	40-59% retained
-4	Severe	20-39% retained
-5	Critically severe	0-19% retained includes local extinction

Note that the percentages applied to severity ratings associated with gains in abundance are strongly non-linear[10] and that negative and positive percentage changes are not symmetrical (Appendix Figure 4; King *et al*. 2003).

For each year of the hydrological record, and for each ecosystem indicator, the severity rating corresponding to the value of a driving indicator is read off its Response Curve and converted to a percentage change. The severity ratings for each driving indicator are then combined to produce an overall change in abundance for each season, which combined provide an indication of how abundance, area or concentration of an indicator is expected to change under the given flow conditions over time, relative to the changes that would have been expected under baseline conditions in the catchment.



Appendix Figure 4 The relationship between severity ratings and percentage abundance lost or retained as used in DRIFT and adopted for the DSS. (Baseline is always = 100%).

A.2.2. Integrity ratings

Integrity ratings are on a scale from 0 to -5.

The integrity ratings are calculated by assigning a positive or negative sign to changes in abundance depending on whether an increase in abundance is a move towards natural or away. The integrity ratings for each indicator are then combined to provide a discipline level Integrity score. Discipline level integrity scores are in turn combined to provide an overall site level Integrity Score, which is used to place a flow scenario within a classification of overall river condition, using the South African Eco-classification categories A to F (Appendix Table 2; Kleynhans 1996; Kleynhans 1999; Brown and Joubert 2003).

The ecological condition of a river is defined as its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on a temporal and spatial scale that are comparable to the natural characteristics of

[10] The non-linearity is necessary because the scores have to be able to show that a critically-severe loss equates to local extinction whilst a critically severe gain equates to proliferation to pest proportions.

ecosystems of the region. As an example, if the baseline ecological status (BES) of a river is a B-category, and there is a decrease in a fish species which is a move away from natural, this will cause the integrity score to be more negative, representing movement in the direction of categories C to F.

Appendix Table 2 Definitions of the Baseline Ecological State (BES) categories (after Kleynhans 1996).

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 completely altered and the changes are irreversible.

Overall Integrity Scores are calculated for the ecosystem as a whole, i.e., the combined effect of changes in the indicators at each site. The results can be plotted as overall Integrity Score (y-axis) vs. percentage or volume of MAR (x-axis) or, where there are relatively few points, as a plot of Integrity Scores per site, which allows for easy comparison between sites. The categories represent points along a continuum, thus the 'divisions' between the categories are only guides as to the general position at which the ecological condition might be expected to shift from one category to the next. Furthermore, the rules for the integrity categories were developed on rivers outside of the Republic of Congo, and have not been tested on the Upper Trishuli River. They provide an indication of the relative categories associated with each scenario and should not be misconstrued as an absolute prediction of future condition.

A.3. IDENTIFICATION OF ECOLOGICALLY-RELEVANT ELEMENTS OF THE FLOW REGIME

One of the main assumptions underlying the DRIFT EFlows process is that it is possible to identify ecologically-relevant elements of the flow regime and isolate them within the historical hydrological record. Thus, one of the first steps in the DRIFT process is to identify these ecologically-important flow indicators. To do this, the flow provided for the river in question is used.

The seasons used in DRIFT are:

- Dry season
- Transitional season 1
- Flood season
- Transitional season 2

The rules for defining the seasons are provided in Appendix Table 3. Due to the moving nature of the seasons, start and end dates are defined for every year of the hydrological time-series.

Appendix Table 3 Rules for defining the end of the four ecological seasons

Season	How the end of the season was defined
Dry Season	A multiple of the minimum dry season discharge
Transition 1	A multiple of the minimum dry season discharge
Flood Season	A multiple of the mean annual discharge
Transition 2	A multiple of the mean annual discharge, together with the recession rate calculated over a number of days

A.4. MAJOR ASSUMPTIONS AND LIMITATIONS OF DRIFT

Predicting the effect of flow changes on rivers is difficult because the actual trajectory and magnitude of the change is additionally dependent on so many other variables, such as climate, sediment supply and human use of the system. Thus, several assumptions underlie the predictions. Should any of these assumptions prove to be invalid, the actual changes may not match the predicted changes. This does not necessarily make the predictions themselves incorrect or invalid, but simply means that the surrounding set of circumstances that support the predictions has changed.

The following important major assumptions apply:

- The baseline hydrology closely approximates the actual flow conditions in the river over the period of record.
- Different parts of the flow regime sustain the river ecosystem in different ways. Changing one part of the flow regime will change the river in a different way than will changing another part.
- It is possible to identify ecologically-relevant elements of the flow regime and isolate them within the historical hydrological record (see Section A.3)
- 2016 conditions were used as a Baseline for predicting change, and change was expressed as a percentage move towards or away from the BES.
- Predicted changes in ecological status are relative to the BES (2016).
- Predictions are based on a 47-year horizon.

The main limitation is the paucity of data. This is a universal problem, as ecosystems are complex and we will probably never have complete certainty of their present and possible future characteristics. Instead it is essential to push ahead cautiously and aid decision-making, using best available information. The alternative is that water resource development decisions are made without consideration of the consequences for the supporting ecosystems, eventually probably making management of sustainability impossible. Data paucity is addressed in the DRIFT process by accessing every kind of knowledge available - general scientific understanding, international scientific literature, local wisdom and specific data from the river under consideration or from similar ones – and capturing these in a structured process that is transparent, with the DSS inputs and outputs checked and approved at every step. The Response

Curves used (and the reasoning used to construct them) are available for scrutiny within the DSS and they, as well as the DRIFT DSS, can be updated as new information becomes available.

A second aspect of the paucity of data is that it is neither known what the river was like in its pristine condition nor exactly how abundant each ecosystem aspect (sand bars, fish, etc.) was then or is now. To address this, all DRIFT predictions are made relative to the baseline situation (there will be a little more, or a lot less, than today, and so on).

These inherent uncertainties also mean that the trends and relative position of the scenarios are more reliable predictors of the impacts of the scenarios than are their absolute values. Also, DRIFT is designed to predict overall condition, and focusing on one indicator to the exclusion of others is not recommended.

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Appendix F
Climate Change Risk Assessment

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Upper Trishuli-1 Hydropower Facility

Climate Change Risk Assessment

Final Report

Cloudwater, LLC

23 November 2016

Contents

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Acronyms and Abbreviations

APHRODITE	Asian Precipitation - Highly Resolved Observation Data Integration Towards Evaluation
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
DHM	Nepal Department of Hydrology and Meteorology
GCM	General (Global) Circulation Model
GPCC	Global Precipitation Climatology Centre
HYMOD_DS	Hydrologic Model for Distributed System with Glacier Module
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
MGHPCC	Massachusetts Green High-Performance Computing Center
NWEDC	Nepal Water and Energy Development Company
RGI	Randolph Glacier Inventory
SNOW-17	Snow Accumulation and Ablation Model adapted for HYMOD_DS
UT-1	Upper Trishuli 1 hydropower facility

1. **Problem Description and Risk Context**

1.1 Introduction

This document describes the methods and initial results for the comprehensive climate change risk assessment of the Upper Trishuli-1 hydropower project. The methods described here represent the most advanced approach for assessing climate change risks and its uncertainty. The approach uses a risk assessment framework that accounts for risks and uncertainty associated with climate change and observational uncertainty that characterizes development in the Himalaya.

The focus of this analysis is to identify possible risks to the UT-1 design that may arise due to climate change. Risk screening will consist of literature review, data analysis, and original modeling and risk analysis using the decision-scaling methodology. In addition, where plausible risks are identified, adaptation options will be proposed and reviewed. Adaptation is discussed in Chapter 3 of this report. The primary risks to be addressed include:

- Reductions in streamflow, especially low flow season
- Extreme streamflows, including floods
- Changes to rain, snow and snow melt
- Changes in streamflow and effects on sedimentation and landslides
- Disease risks

The priority risks associated with climate change are: (1) increases in extreme streamflows that could jeopardize the physical integrity of the headworks; and (2) decreases in low season flows that could jeopardize the success of the project. Thus of primary importance is understanding the hydrologic response of the system to climate change. This section presents early findings of hydrologic modeling aspects of the risk assessment, and presents no hydropower, economic, or other results from the water system model. Results from the system model will be forthcoming in subsequent versions of the climate change risk assessment and risk management reports.

Other non-climate factors (e.g., economic, political, demographic) are not modeled probabilistically (i.e., using the stress test approach), but are described based on information collection and literature review. These potential impacts include: 1) potential irrigation development upstream of the dam site; 2) potential ecosystem services alteration as addressed in Yonzon (2010); 3) dam structure safety; and 4) public health (as concerns are identified). The expectation is that at this stage of analysis the concerns are likely to be adequately addressed through the information investigation and summarized in the final report. Hydro Lab, based in Kathmandu, has provided background and input on the dam safety and structural failure related concerns. HydroLab has expertise in dam structure, physical modeling and sedimentation, and have provided data and information as needed. We do not anticipate the need for physical modeling of sedimentation processes within this analysis.

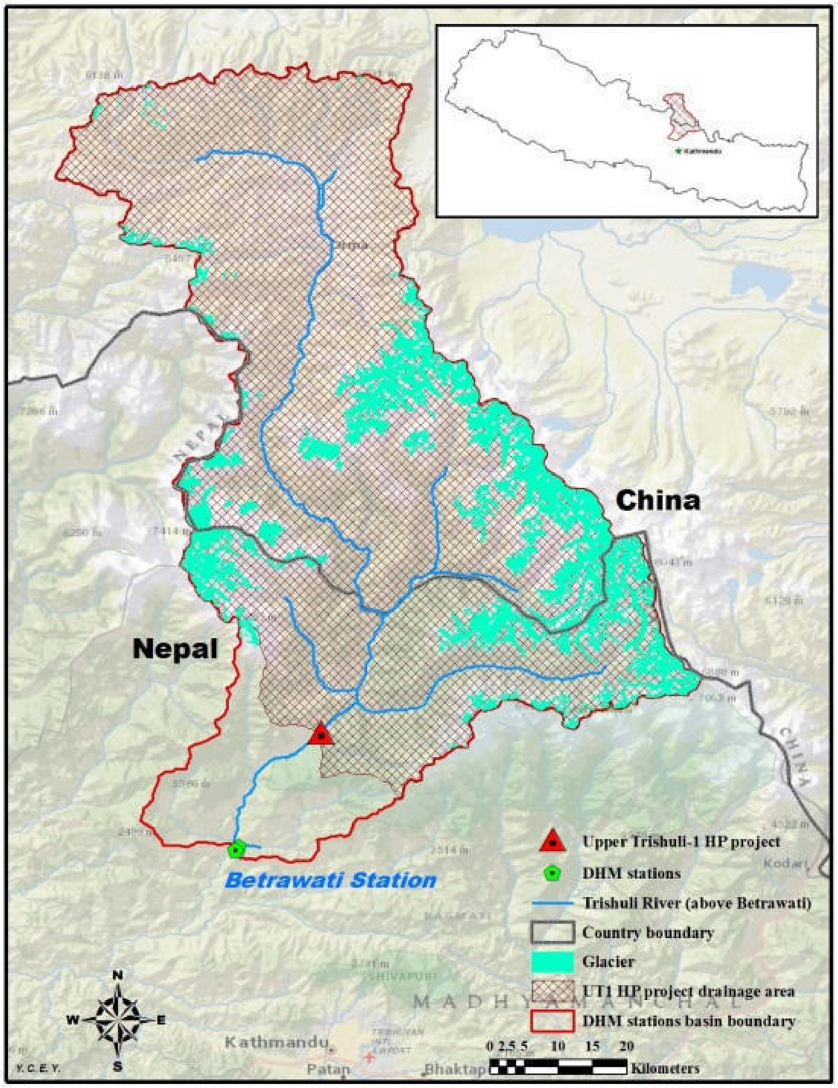


Figure 1. The Upper Trishuli Basin includes territory in Nepal and China. The Betrawati station is the source of hydrologic data. The UT-1 project site is indicated by the red triangle.

1.2 The Upper Trishuli-1 Hydropower Project

The Upper Trishuli-1 Hydropower Project (UT-1) is a proposed hydropower project at the upstream of Trishuli River in Nepal (Figure 1). It is a run-of-the-river project with average gross head of 342 meters (NWEDC, 2014). The nearest Department of Hydrology and Meteorology (DHM) station is Betrawati with drainage area of 4850 km^2 (apprx. 38% in Nepal). Drainage area for the dam site is about 4157 km^2 (1251 km^2 in Nepal). Based on the Randolph Glacier Inventory (RGI version 3.2) database, the total area covered by glaciers is about 642 km^2 (above Betrawati). Sharma (1993) explained that the lowest streamflow occurs in March, which indicates the beginning of the melting season for snow and glacier. Snow and glacier meltwater continue to contribute significantly to streamflow through May and into June.

There are up to 14 projects planned for the Upper Trishuli River, representing 838 MW of hydropower capacity, a number greater than the total current hydropower capacity of Nepal. The UT-1 project is the largest project among these 14. Since it is a run-of-the-river project, the amount of power it generates will be sensitive to changes in the volume and timing of streamflow. Both climate change and changes due to socio-economic shifts are possible sources of change to streamflow, though current upstream development levels are relatively small in the watershed. To the best of our knowledge, there is no major development planned in the undeveloped Chinese part of the basin (Jilong County), and there is little current or planned irrigation in the Nepalese part of the basin. Therefore, the potential effects of climate change, including possible effects on sedimentation rates and extreme flows, are the major concerns for decision-making.

1.2 Hydrological and Meteorological Data

Hydrologic and meteorological data were collected from a variety of sources. Meteorological data such as precipitation and temperature are primary inputs to the hydrologic model. Gridded daily temperature and precipitation products with a spatial resolution of 0.25° are available for the period 1961-2007 from the Asian Precipitation Highly Resolved Observational Data Integration Towards Evaluation (APHRODITE) dataset (Yatagai et al., 2012). The APHRODITE daily temperature data are directly used in the modeling process. However, our preliminarily data analysis confirmed the downward bias in APHRODITE precipitation previously reported by Palazzi et al. (2013). Therefore, for precipitation input to the hydrologic model the precipitation product from the Global Precipitation Climatology Centre (GPCC) dataset (Schneider et al., 2014) was downscaled both spatially (from 0.5° to 0.25°) and temporally (from monthly to daily) using the APHRODITE's spatial and temporal pattern.

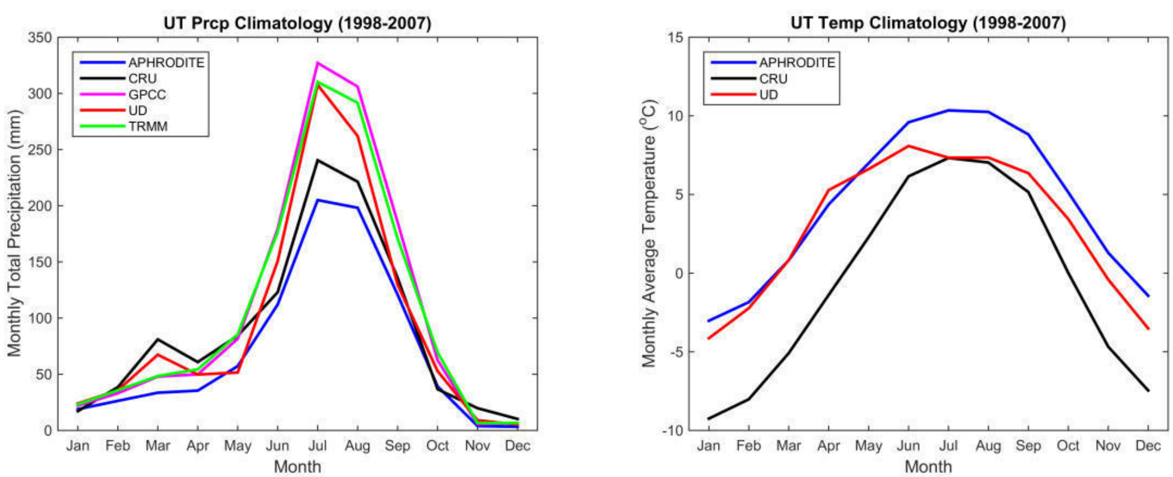


Figure 2. Comparison of precipitation and temperature data from multiple sources. The differences between datasets reflect the difficulties associated with estimating meteorological data in locations with sparse observations and challenging terrain.

Hydrologic data were collected for the two DHM stations located within the basin (Table 1). Finally, climate change projections provided by the current and previous generations of climate modeling intercomparison projects were utilized to explore feasible climate conditions in the future.

Table 1 Two DHM station at the Upper Trishuli River.

Station NO	River	Location	Lat (deg)	Lon (deg)	Elev (m)	Drain area (km^2)	Start year	End year
446.8	Phalankhukhola	Betrawati	27.97	85.19	630	162	1971	1995
447	Trishuli	Betrawati	27.97	85.18	600	4110	1977	2006

1.3 Background on Climate Change in the Himalaya

This section provides a brief description of climate change within a regional context based on the latest peer reviewed scientific literature. The "Greater Himalaya" is defined as the region including the Hindu-Kush-Karakorum mountains and the Himalayan mountains. More than 1.3 billion people rely on the water originated from the Greater Himalaya. Among the challenges facing South Asia, water resources management for sustainable water supply, agricultural production and energy generation in the region's great river basins are most pressing, due to the complex climatic/hydrologic regime (snow/glacier and monsoon) vulnerable to climate change and the potential for both inter- and intra-basin political conflict.

The first step in exploring the regional climate change impact is to identify possible trends in the historical climate data. In the Indus Basin, for example, a tendency was found that the winter is warming and the summer is cooling (Flowler and Archer, 2006; Ahmad et al., 2012; Bocchiola and Diolaiuti, 2013), though there is not a general agreement on the magnitude of the precipitation change. Though previously studies have not identified a statistically significant historical trend in annual precipitation, winter precipitation may be increasing (Archer and Fowler, 2004; Ahmad et al., 2012; Bocchiola and Diolaiuti, 2013). For example, Khattak et al. (2011) and Sharif et al. (2013) explain that streamflow in the upper Indus Basin is predominantly influenced by winter precipitation, and that increasing trends in winter steamflow and decreasing trends in summer streamflow have been observed.

Jain and Kumar (2012) analyzed the precipitation data for all of India and reported that precipitation in the Ganges basin exhibits no significant trend, and that precipitation in the Brahmaputra basin is decreasing. Both the upper Ganges (India-Nepal) and lower Ganges (India-Bangladesh) show decreasing trends in precipitation extremes (Adel, 2002; Duncan et al., 2013). Following on the precipitation result, other studies suggest that the streamflow in the monsoon season also has a decreasing trend (Sharma and Shakya, 2006).

In the upper Brahmaputra Basin, there is a general agreement on the presence of an increasing trend in both temperature (especially in winter) and precipitation (especially in spring) (Ge et al., 2004; Yao, 2008; Xu et al., 2009), which results in a slightly increasing trend in streamflow (Liu et al., 2007; Gao et al., 2008; Zhang et al., 2010). However, Tsao et al. (2005) observed no streamflow change in the major rivers originating from the

Qinghai-Tibetan Plateau, and Deka et al. (2013) pointed to a decreasing historical precipitation in the lower Brahmaputra basin.

The uncertainty in the historical trend is amplified in the future projections (see Figure 3). The latest generation of climate projections of the Intergovernmental Panel on Climate Change (IPCC) is called the Coupled Model Intercomparison Project Phase 5 (CMIP5). The CMIP5 ensemble shows a very large uncertainty in climate-change-related risks to the Greater Himalaya region. In the Greater Himalaya in general, uncertainty has increased since the previous generation of IPCC emission scenarios (the Coupled Model Intercomparison Project Phase 3, CMIP3); however, this is not the case in the Upper Trishuli basin (as shown in Figure 3). This uncertainty might be mainly due to the poor ability of the General Circulation Models (GCMs, also known as Global Climate Models) to represent both the snow/glacier effects and monsoon mechanism. As a result, a number of studies have attempted to discern and summarize the climate change impacts on the Greater Himalaya region. Immerzeel et al. (2010) concluded that huge differences exist between Himalayan basins in the extent to which climate change is predicted to affect water availability and food security. This is mostly attributable to differences in snow/glacier melt contribution to the streamflow. A summary of component contribution to streamflow by Savoskul et al. (2013) concluded that though glacier and snow melt contribute only small fractions (7% and 3%, respectively) to annual runoff in the Ganges and the Brahmaputra rivers, the glacier and snow melt contribution to streamflow in the Indus basin is on the range of 35-40%. The nonrenewable component in the total glacier runoff has increased from 16-30% to 26-46% since 1961 throughout the Greater Himalaya region, suggesting that glaciers are melting down in most (if not all) basins. Miller et al. (2012) explained that climate change may increase rainfall in the future, leading to increased flows in the Ganges and Brahmaputra, but with greater variability. The expectation of reduced snow/glacier runoff with increased precipitation variability makes it difficult to estimate future water availability in the Indus. According to Kulkarni et al. (2013), large-scale modeling results indicate that rainfall may be 40–50% more variable in the Central and Eastern Himalaya at the end of this century.

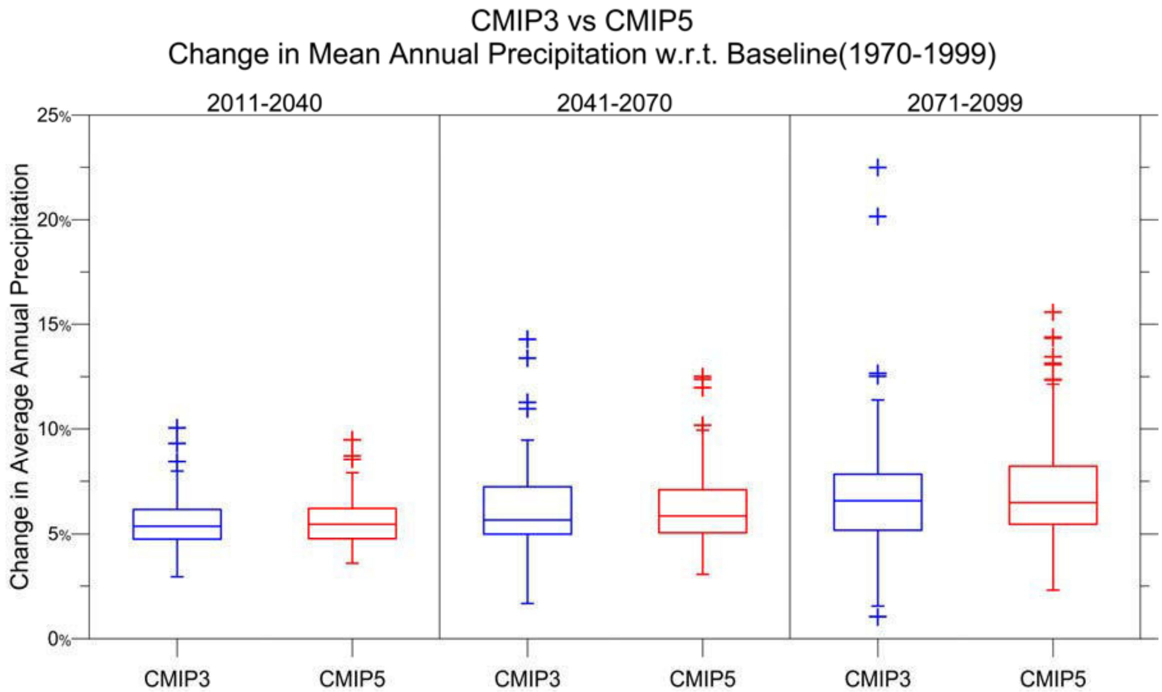


Figure 3. Change in mean annual precipitation with respect to baseline (1970-1999).

Specific to the Central Himalaya (including Nepal), Sharmar (1993) summarized the role of meltwater in major rivers of Nepal and reported that the snow-fed rivers show a rise in streamflow during the pre-monsoon period (April to mid-June) with meltwater contribution exceeding 30% in May. The role of meltwater becomes less important as compared to the role of groundwater and rainfall after May. Shrestha and Aryal (2011) explained that among the large rivers in Nepal, Karnali and Sapta Koshi show a decreasing trend, and Narayani (Kali Gandaki) shows an increasing trend. However, due to the short record and high inter-annual variability in discharge data, these observed trends in river discharge are not statistically significant. Regarding climate change impacts, Lutz et al. (2014) showed an increase in streamflow through 2050 caused primarily by an increase in precipitation in the upper Ganges. Likewise, Shrestha and Aryal (2011) projected an increasing trend in streamflow in the Kali Gandaki-Narayani river system, and argued that the catastrophic water shortages forecasted by some experts are unlikely to happen for many decades (if at all). However, the increases in precipitation and streamflow variability and the great uncertainties about future glacier meltwater availability that accompany projections of increasing streamflow indicate that the hydropower sector in Nepal continues to carry greater climate change risk than most other sectors (Bhusal, 2014). Greater unreliability of dry season flows, in particular, poses potential risks to hydroelectric energy production in the dry season when electricity prices are highest.

2. Methods

The decision scaling approach to climate change risk assessment applied to UT-1 requires four modeling subsystems: 1) a weather generator (algorithm for generating timeseries of potential future climate); 2) a hydrologic model (to translate climate timeseries into timeseries of streamflow); 3) a water resources system model (to translate streamflow timeseries into timeseries of hydropower production and other water system performance metrics of interest); and 4) procedures for analyzing and describing the risks to the water system (such as statistical tools and graphical concepts). An example schematic of the modeling system is provided in Figure 4. The individual components are described below.

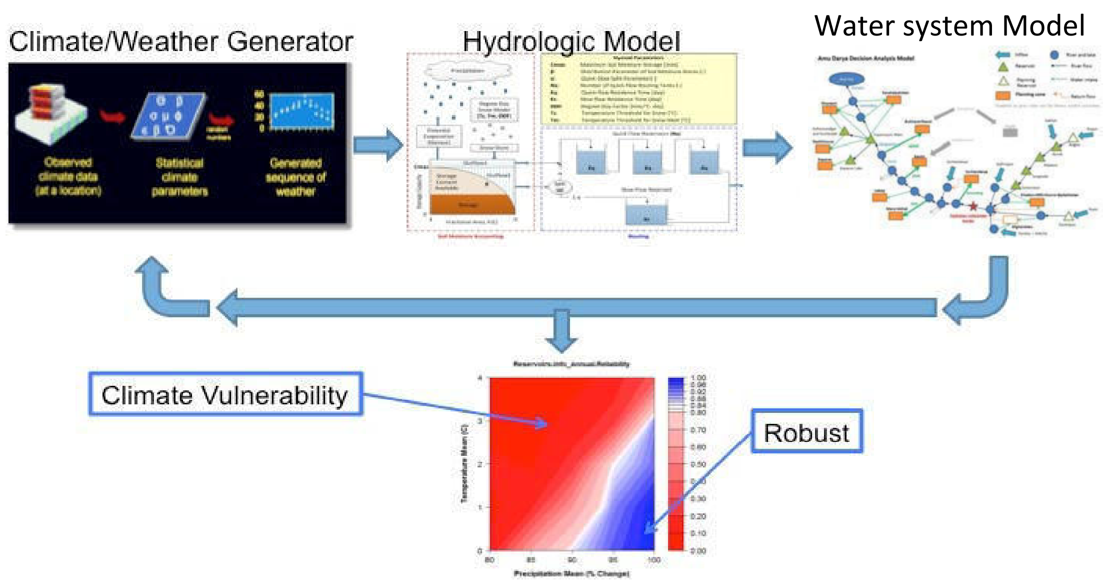


Figure 4. Schematic diagram of the decision scaling framework as applied in this study. The figure at the bottom represents a climate response function, which indicates project performance over the range of plausible climate change.

This section includes description of the glacial-hydrologic model, with calibration and validation results, the water resources system model design, and the approach for climate change stress-testing. In addition to the technical approaches described here, the work is underpinned by literature reviews, personal interviews and other non-modeling research methods. Non-modeling research methods are not described in detail here.

2.1 Distributed Glacio-hydrologic Model

The distributed glacio-hydrologic model applied for this analysis is the HYMOD_DS. The HYMOD_DS is the modeling system created by the University of Massachusetts Hydrosystems Research Group and applied by Cloudwater, LLC, to mountainous regions with sparse data. The model is designed for parallel processing on supercomputers, allowing calibration by the Massachusetts Green High-Performance Computing Center (MGHPCC), a major advantage over other modeling methods. The HYMOD_DS is particularly suited for the UT-1 project. The prototype of the model was built for a World Bank supported study of the Kabul Basin (Wi et al., 2015) and the Brahmaputra Basin (Yang et al., 2014b). The original HYMOD model (Boyle, 2001) is a lumped parameter, rainfall excess model composed of a soil moisture accounting module. Wi et al. (2015)

introduced a routing module, which allows runoff from each cell to be hydrologically traced to the basin outlet, creating a spatially-distributed version of the model. In addition, a temperature-based snow/glacier module was developed to explicitly model the dynamics of melting snowpack and glaciers, with resulting contributions to streamflow. The model structure of the HYMOD_DS modeling system is described in detail in Wi et al. (2015).

The snow/glacier module is critical for the UT-1 project, as preliminary data analysis indicates that streamflow in the basin heavily influenced by snow/glacier melt. In this application, we have modified the SNOW-17 snow accumulation and ablation model (Anderson, 2006) as an alternative to our current temperature based snow module. The SNOW-17 is a temperature index model that determines the energy exchanges across the snow-air interface. To consider the variation in the amount of snow accumulation and ablation and the timing of melt at different elevations of mountainous regions, we divide UT-1 watershed into several elevation zones and apply SNOW-17 in distributed fashion. A similar concept for the glacier module is developed and the glacier geometry, ice flow, and total glacier mass balance are modeled by elevation zone with a temperature-energy index equation. The conceptual figure of this advanced glacio-hydrologic distributed model is given in Figure 5. The initial analysis described in this report is based on the current version of the model.

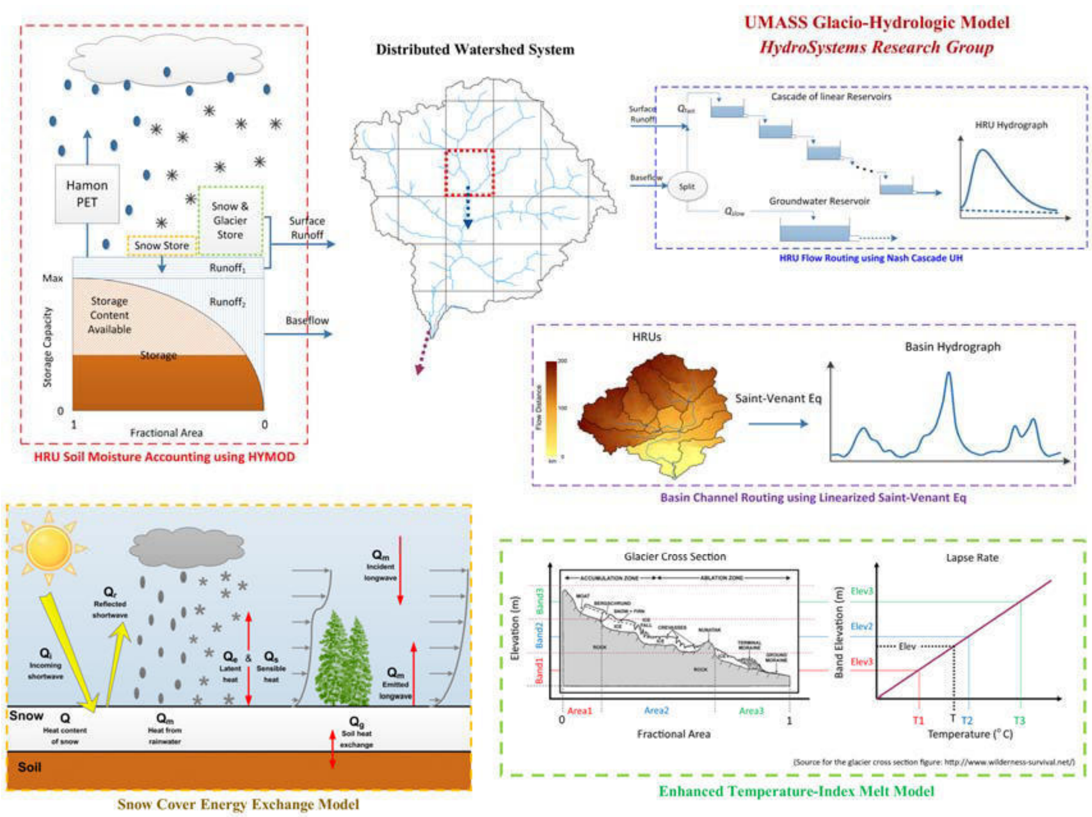


Figure 5. Advanced glacio-hydrologic distributed model by UMass Hydrosystems Research Group.

The hydrologic modeling system used to evaluate streamflow responses to climate change based on direct physically modeling. This includes changes to extreme hydrologic events (e.g., floods) as well as low season flow rates. With the enhanced snow/glacial module specifically designed for rivers originating from the Himalayan region, the results are a best available estimate of changes to streamflow as a result of plausible future temperature and precipitation conditions at the project site. Figure 6 shows the high resolution digital elevation model (DEM) used as input to the hydrologic model.

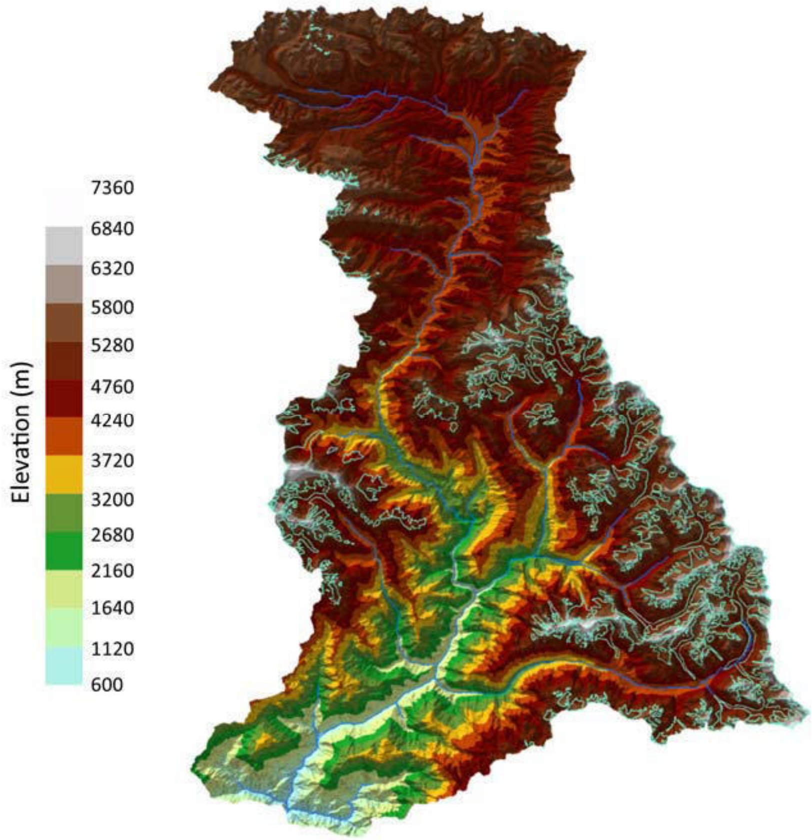


Figure 6. Digital elevation map of the Upper Trishuli Basin.

The model has been calibrated to daily streamflow data at the Betraswati basin. The thirty-eight year record was divided into a calibration and evaluation period. As shown in Figure 7, the calibration results were excellent, with a Nash-Sutcliff Efficiency statistic of 0.88 during the calibration period and 0.90 during the evaluation period. Based on the quality of the calibration and validation results, high confidence can be taken in the model's applicability in the basin.

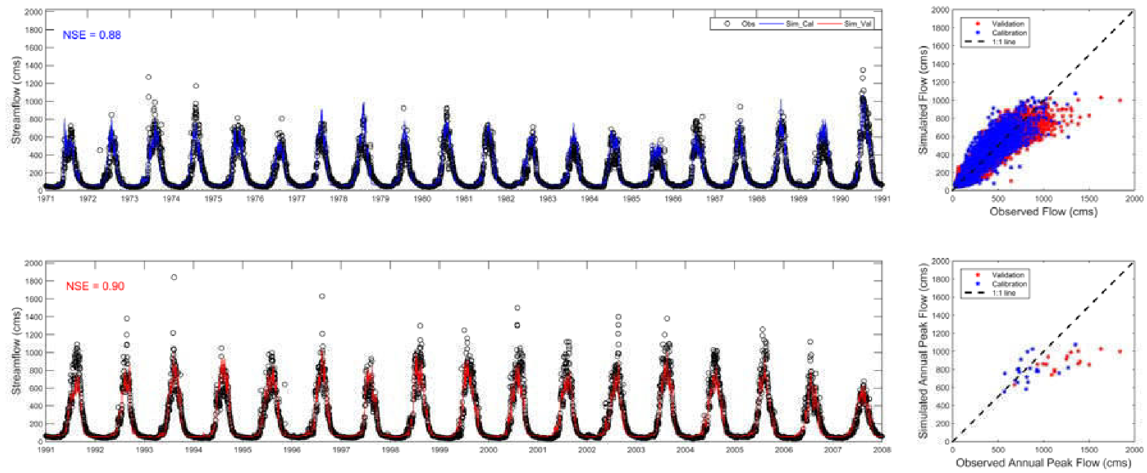


Figure 7. Streamflow from the HYMOD_DS compared to observed data. Blue circles represent the calibration period and red circles represent the results for the evaluation period. Results are generally excellent although some higher extreme flows were not captured.

Figure 8 shows the monthly average hydrograph for inflows to the UT-1 project site, including the contribution of different aspects of the hydrosphere. As expected, the hydrograph exhibits classic monsoonal and mountain hydrology, with a distinct summer peak and winter low flow period. As almost all precipitation occurs during the summer monsoon months, the low flow period is made up primarily of baseflow (groundwater or subsurface flow). Streamflow in summer months consists of meltwater from snow and glaciers due to warmer temperatures, in addition to rainfall from the monsoon. Understanding the contributions of the components of the hydrosphere allows the development of expectations regarding changes in streamflow patterns with climate change.

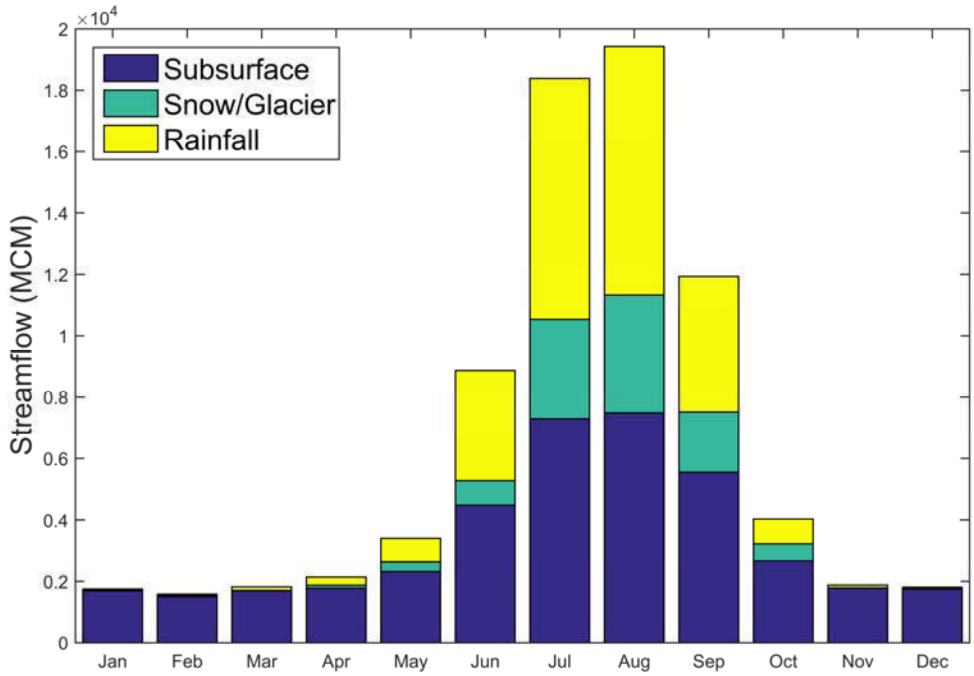


Figure 8. Annual hydrograph of streamflow in the Upper Trishuli Basin showing contributions from subsurface (blue), snow and glacial melt (green), and rainfall (yellow).

2.2. Water Resources System Model

In order to translate changes in streamflow into impacts on hydropower generation and downstream flow conditions, a water resources system model has been developed. Typically, water systems models are either constructed as simulation models, with reservoir operations following prescribed rules, or as optimization models, with reservoir operations guided by an objective function (e.g., maximization of hydropower generation subject to constraints). The model developed as part of this analysis is of the simulation type.

The water resources systems model is quite simple in this case of run-of-river hydropower with no storage or reservoir operations to be considered. For this purpose a simple system model was developed in R, the mathematical modeling language. The water resources system model computes hydropower generation and its profits under different inflow conditions, which are provided by the hydrologic model. The model could be expanded to consider downstream water requirements (agricultural, domestics and/or ecological purposes) and demonstrate tradeoffs between alternative water uses, although this is not considered needed at the moment (see Section 3.4 “Effect of changes in upstream water demand”).

Figure 9 shows the streamflow exceedance probability for the bias-corrected Betrawati[1] stream gage, just downstream of the proposed site of the UT-1. Average daily streamflow values in *m^3/s* were ordered and assigned exceedance probability using Weibull plotting position. The values presented are in close agreement with those presented by the client in reference to the prefeasibility study, in which the design flow was estimated to be 76 m^3/s (which in the analysis presented here has been estimated as the Q50 flow with a value of 77 m^3/s).

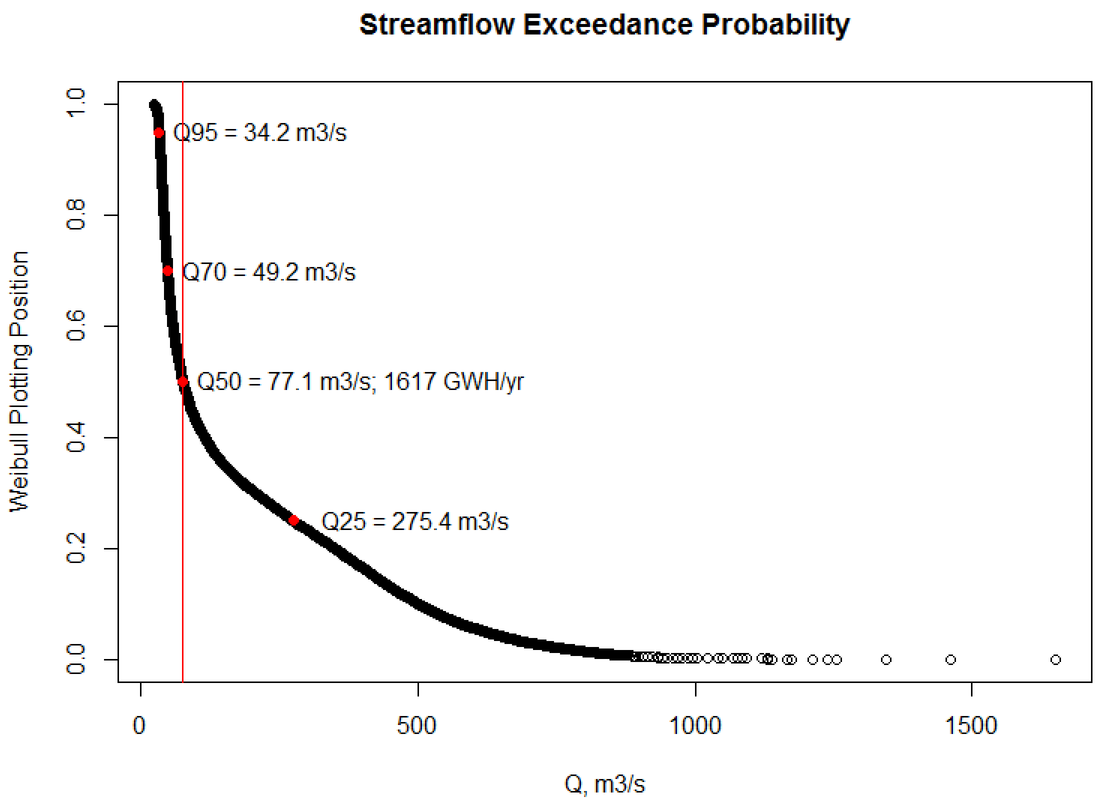


Figure 9. Bias-corrected Betrawati streamflow exceedance probability (Jan 1967-Dec 2010). Red vertical line indicates design flow of 76 m^3/s.

The streamflow data in Figure 9 were then converted to GWhr/day using equation (1), which is a simple planning relationship:

$$\frac{GWhr}{day} = 0.002725 \cdot Q\left[\frac{MCM}{day}\right] \cdot H[m] \cdot e \qquad (1)$$

with net head, H = 332 meters, and the efficiency of the conversion of mechanical energy

[1] As shown in Figure 1, Betrawati station is downstream of the proposed location of the intake for the UT-1 hydropower plant. The catchment area of Betrawati station is 4850 km^2, and the catchment area of the UT-1 facility is 4350.9 km^2. Daily flow values from the Betrawati station were therefore multiplied by the ratio 0.8971 (4350.9/4850) in better represent the amount of streamflow available at the upstream UT-1 site.

into electrical energy, e = 0.9. Equation (1) is derived from the fundamental physics describing the translation of potential energy into kinetic energy. A cubic meter of water, weighing 10^3 kg, falling a distance of one meter, acquires 9.81 x 10^3 joules (Newton-meters) of kinetic energy. A Watt is a unit of power, equal to a Joule of energy expended per second. Equation 1 expands the example of a single cubic meter of water falling a single meter to the case of many millions of cubic meters of water falling many meters each day. The coefficient 0.002725 is an aggregate unit conversion. Detailed explanation of the derivation and utility of (1) is available in *Loucks and van Beek* [2005].

The potential (un-capped) hydroelectric power exceedance probability is presented in Figure 10. The horizontal red line in Figure 10 shows the GWH50 (daily hydropower with exceedance probability of 50%) for the 216MW facility based on the prefeasibility study (Q50 = 76 m^3/s; $GWH50_{cap}$ = 4.2 GWh/day). It nearly passes through, but is somewhat less than, the red dot for GWH50 = 4.4 calculated using data available for this analysis.

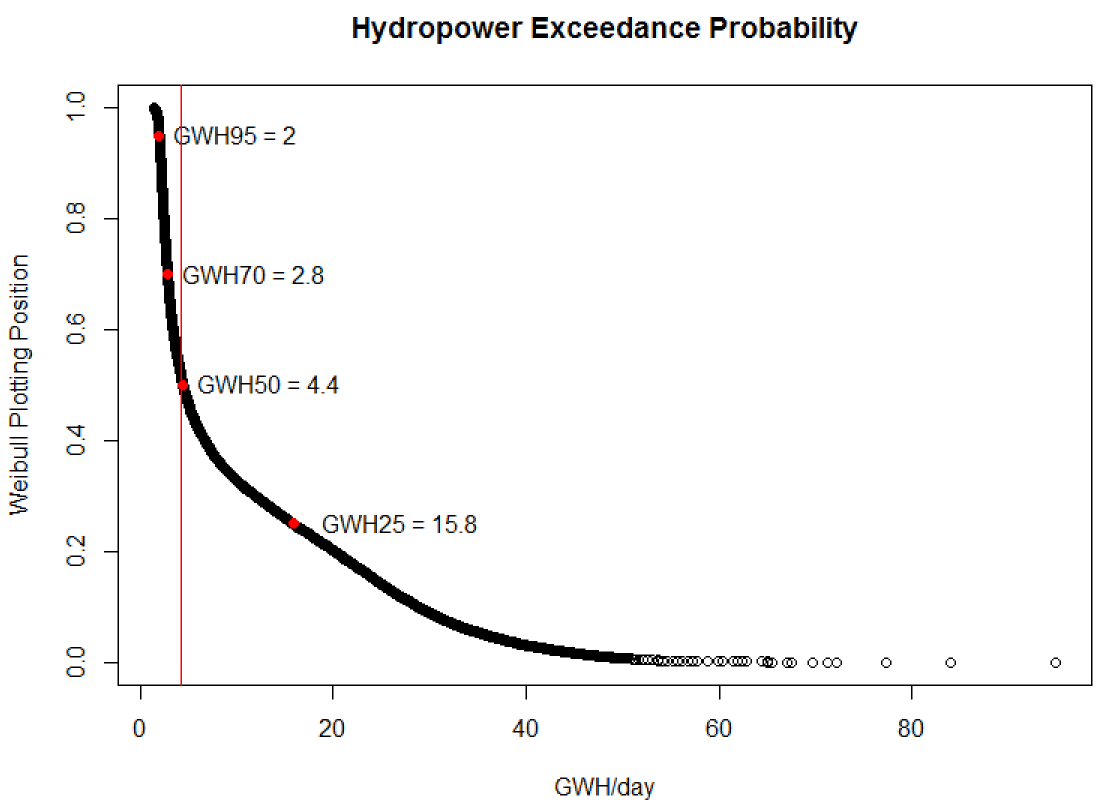


Figure 10. Theoretical potential (uncapped) hydropower exceedance probability. Red dots are calculated exceedance probabilities of uncapped hydropower production. Red line is production presented in UT-1 project documents.

Figure 11 provides perspective on the capacity of the 216 MW facility relative to the seasonal peak flows of hydropower potential at the site of the UT-1. The time series of hydropower production in Figure 11 is calculated by applying (1) to the time series of bias-corrected streamflow at Betrawati. The horizontal red line in Figure 11 locates the capacity of the 216 MW facility. Hydropower production potential in excess of the red line would not be generated with a 216 MW facility.

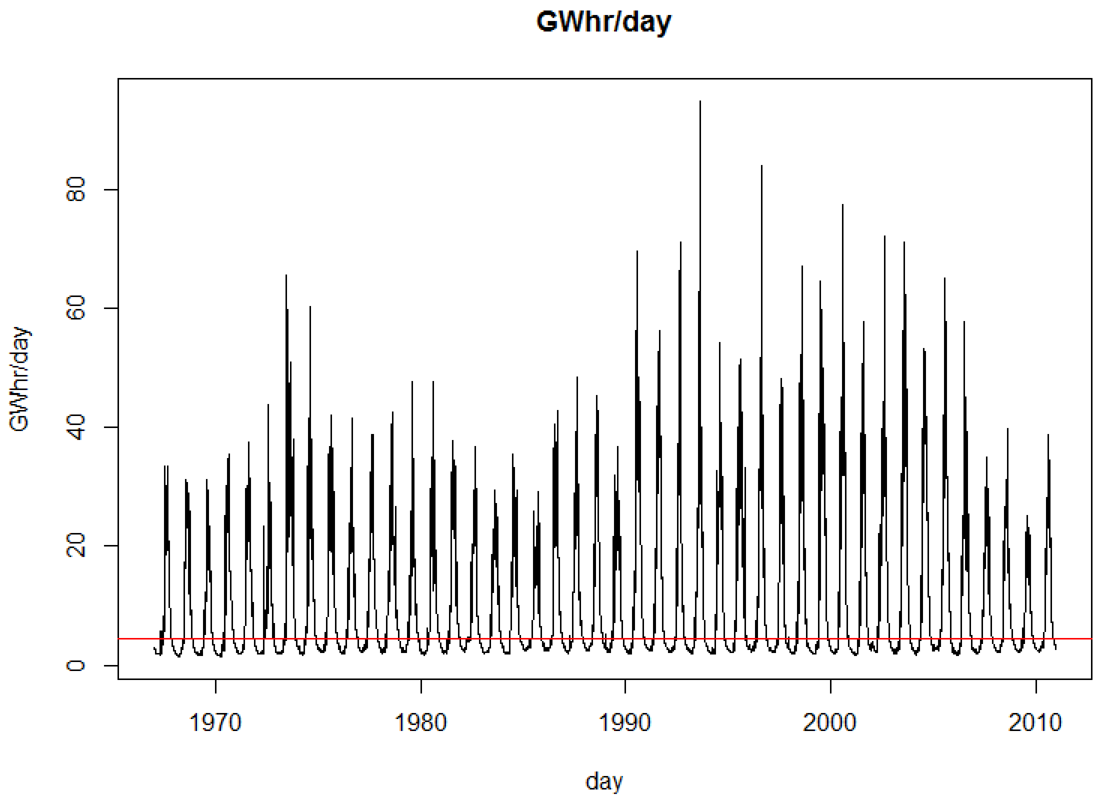


Figure 11. UT-1, 216 MW PROR @ Q_{50}, max daily GWhr/day generation relative to daily timeseries of GWhr potential (red line).

The NPV was calculated using (2):

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0 \quad (2)$$

where:
C_t = net cash inflow during the period.
C_0 = initial investment
r = discount rate
t = number of time periods (in our case, months)

Table 2 summarizes the design parameters used by the hydropower model to estimate system performance. Most values are provided by the client, or taken from the project documents. A subset of the values (O&M cost, discount rate, and turbine efficiency) were estimated using engineering judgment and previous experience in the region (esp., the Upper Arun Hydropower Project).

Table 2 UT-1 Hydropower project design parameters.

Parameter	Value
Catchment Area	4350.9 km^2
Design Discharge	76 m^3/s
Net Head*	332 m
Installed Capacity	216 MW
Total Annual Energy Production	1532 GWh
Capital Cost	$580M
Annual O&M Cost**	$2 \cdot (125000 \cdot (kWhr\_cap/1000/24)^{0.65})$
Discount Rate	5%
Electricity Selling Price	Dry season (Nov-Mar) 0.084 $US/kWh Wet season (Apr-Oct) 0.045 $US/kWh
Project Lifetime	30 years (+ 5 yr construction time)
Plant Load Factor	0.817
Turbine Efficiency	0.90

**Gross head is 340.89-343.66 m. Project documents do not present net head. The Upper Arun Hydropower Project included gross head of 509 m and net head of 492 m, with a head "loss" of 17 m. Given the smaller size of the UT-1 facility, 10 meters of head loss was assumed here.*

***The O&M cost equation is an empirical relationship based on the experience of Jim Gordon, a World Bank-sponsored hydropower expert and preferred by hydropower project planners in the World Bank. The original empirical relationship has no coefficient of 2. The coefficient of 2 was added as a factor of safety given the additional costs of operating a hydropower facility in Nepal. The units on the kWhr_cap number are in units of kWh per day of operation. In this case kWhr_cap=5.184x10^6 and kWhr_cap/1000/24 = 216 MW installed capacity. The units on the O&M cost equation are $2015/year.*

2.3. Climate Stress Test

Cloudwater uses a climate stress test as the analytical engine for identifying vulnerabilities of designs or plans and better understanding the performance of a design across a wide range of possible futures. The stress test approach has been described in multiple peer-reviewed journal publications. The process was developed based on research funded by the U.S. National Science Foundation (NSF), National Oceanographic and Atmospheric Agency (NOAA), the Department of Defense (DOD), and the World Bank. The climate stress test is tailored to each study location. In the case of UT-1, the objectives are to better understand how possible climate changes could affect the performance of the investment, whether any vulnerabilities identified require adaptation, and if so, how effective the possible adaptation actions might be.

The climate stress test is an exhaustive exploration of the effects of climate changes and changes in other key factors on the performance of the system. The climate stress test is conducted using a stochastic climate/weather generator that varies weather conditions, linked to a specified climate state, to find the climate states that are problematic for a specific design. The climate/weather generator is used to create time series of daily weather data for a specified time frame (e.g., 50 years) over a specified spatial area that is consistent with a specified climate change. The climate/weather generator is designed such that the mean climate conditions can be changed and then new weather sequences generated that represent the changed climate conditions. In this way, an ensemble of weather time series is created that will test the sensitivity of the system to changes in mean climate conditions (e.g., changes in mean precipitation and temperature) and variability effects (the natural variability of day to day weather and longer spells due to the earth's climate system). The climate stress test allows efficient and exhaustive sampling of the system's responses to all climate changes. It does not depend on climate projections or "downscaling" methods, and thus avoids all the uncertainties that they introduce, including choice of emissions scenarios, GCMs, downscaling, etc., because the climate stress test explores sensitivity to climate change (rather than sensitivity to a particular climate model's projection of the future).

The schematic diagram of the modeling chain presented in Figure 4 was adapted to the specific application of the UT-1 project. The stochastic climate/weather generator creates a timeseries of weather variables that are used as inputs to the hydrologic model. The hydrologic model in turn produces the streamflow that results from the weather trace. The streamflow is then used by the water resources system model to estimate the performance of the system, including the hydroelectricity production and the downstream flows.

The result of the climate stress test is a dataset of project outcomes and the associated values of uncertain factors that cause those outcomes to occur. This dataset is then used to identify the combinations of factors that lead to unwanted outcomes. Note that outcomes will be primarily in the form of cost-benefit analysis results, although other outcomes, such as firm energy level, etc., will also be considered. These combinations of uncertain factors represent scenarios, and since they emerge from the output of the analysis (rather than being used as inputs) they are described as *ex post* scenarios. Since they are scenarios that cause unwanted outcomes, we define them as risk scenarios. Specific data mining tools are used for the definition of ex post scenarios, including cluster algorithms such as the Patient Rule Induction Method (PRIM). With the risk scenarios identified, two additional analyses can be conducted. First, the relative probability of the scenarios can be estimated to provide a relative ranking of risks and level of concern associated with each. Second, if risks appear that are of relatively high concern, adaptations can be assessed to lower the level of concern.

3. Preliminary Assessment of Climate Risks

The focus of this analysis is to identify possible risks to the UT-1 design that may arise due to climate change. The primary risks to be addressed include:

- Reductions in streamflow, especially low flow season
- Extreme streamflows, including floods
- Changes to rain, snow and snow melt
- Changes in streamflow and effects on sedimentation and landslides
- Disease risks

This section presents modeling results on the risks posed by each of the above.

3.1 Hydrologic Response

This analysis has focused on understanding and describing the hydrologic response of the UT-1 contributing area to changes in climate. Figure 12 summarizes the response of mean total annual, dry season, and wet season streamflow to all plausible changes in climate (percent changes to mean annual streamflow are shown in Figure 13). The contours show the value of mean annual streamflow for the climate changes indicated on the x- and y-axes, with blue showing increases in streamflow and red indicating decreases in streamflow. The circles superimposed on Figure 13 indicate the mean climate changes that are projected by downscaled GCMs for this location. The uncertainty in the GCM projections for this basin are illustrated in boxplots in Figure 3.

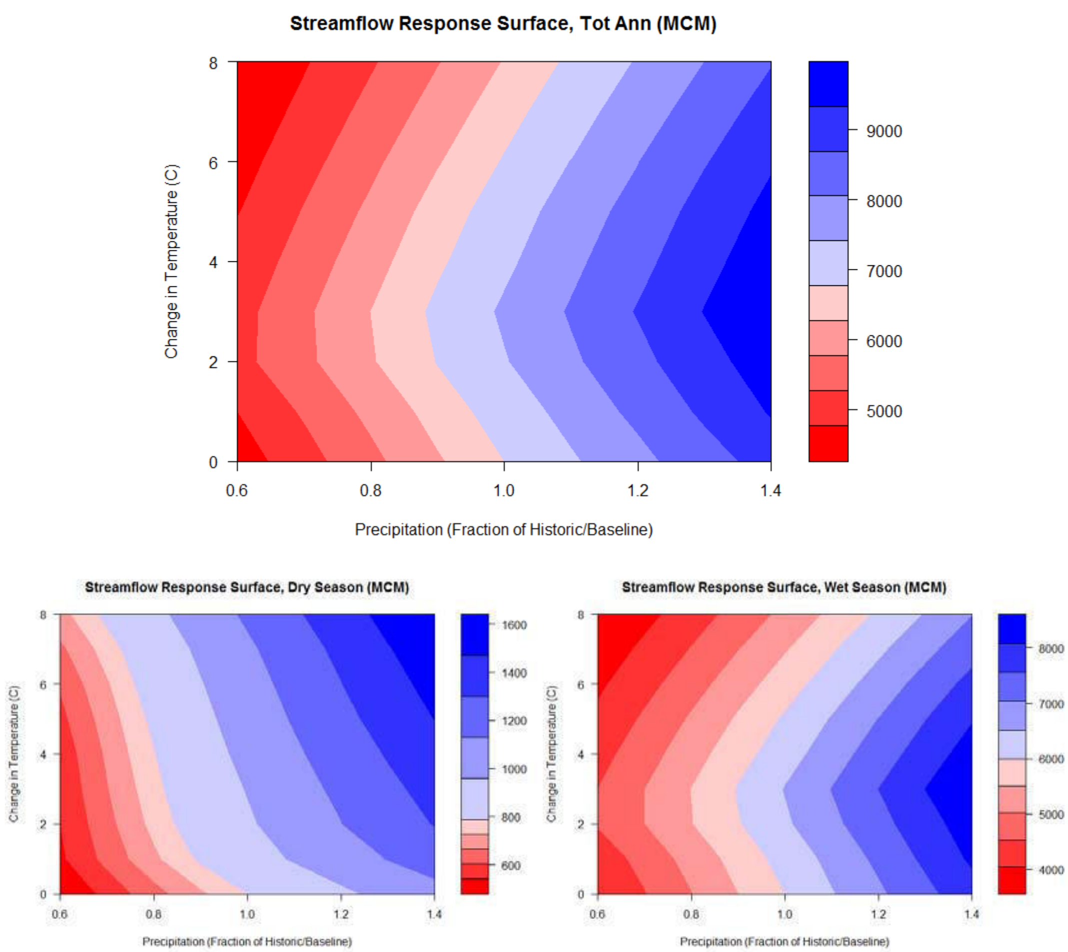


Figure 12. Climate response function of mean annual streamflow in response to changes in precipitation (x-axis) and temperature (y-axis). Streamflow units are MCM/yr (or MCM/season). Blue contours show increases in streamflow and red contours show decreases.

Figure 12 illustrates the 30 year long-term average annual, dry season, and wet season streamflow at Betrawati station, subjected to a range of climate conditions. Precipitation has the dominant effect on streamflow, as demonstrated by the largely vertical contour lines. Streamflow shows a more or less monotonic response to changes in precipitation, i.e., increases in precipitation result in increases in streamflow and decreases in precipitation result in decreases in streamflow.

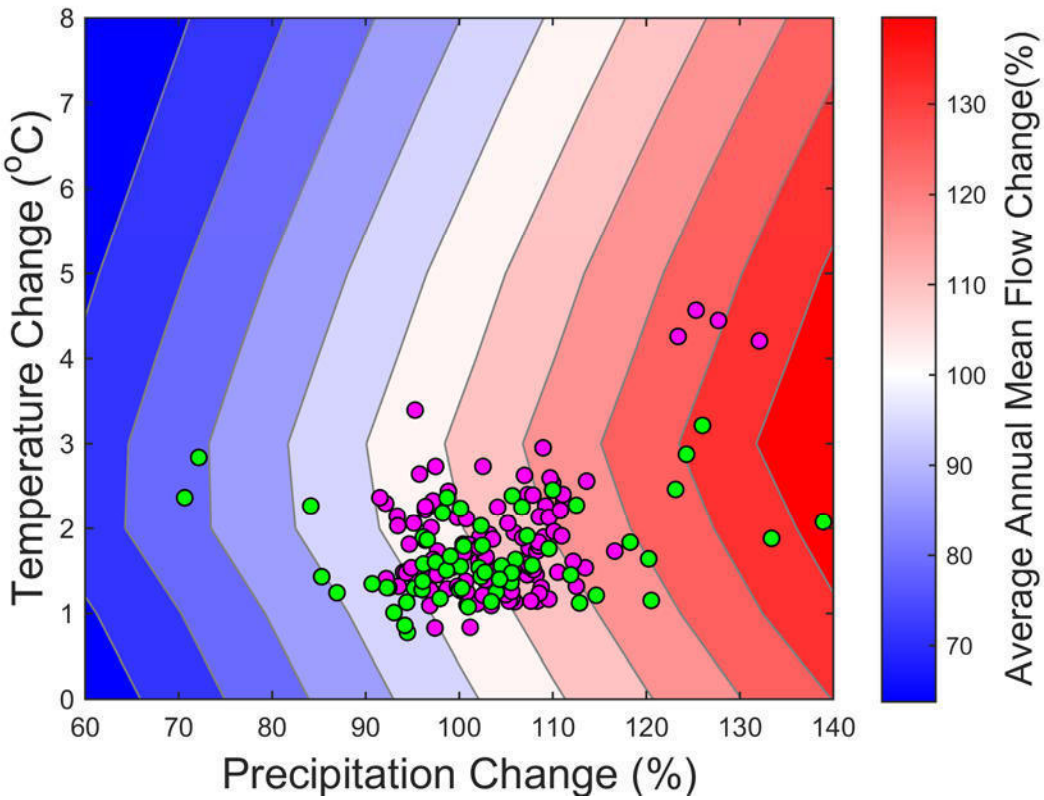


Figure 13. Change in average annual mean flow (% of baseline/historic). Green dots are all CMIP3 climate change scenarios. Purple dots are all CMIP5 climate change scenarios.

Temperature effects are smaller but more interesting. Over the course of the 30-year simulation, a critical inflection point in the flow pattern occurred at an increase in temperature of approximately 3 degrees C. When the system was simulated with temperature increases less than 3 degrees C, the "increased" temperature exhibited a positive effect on streamflow resulting from greater quantities of meltwater contribution from snow/glacier. However, with temperature increases larger than 3 degree C, the streamflow gains are reversed as increasing rates of evapotranspiration and diminishing returns from a shrinking (receding) glacier decreased the total rate of flow (see Figure 14). This phenomenon is especially evident in the wet-season response, as most of the meltwater is contributed after March, the final month of the dry season.

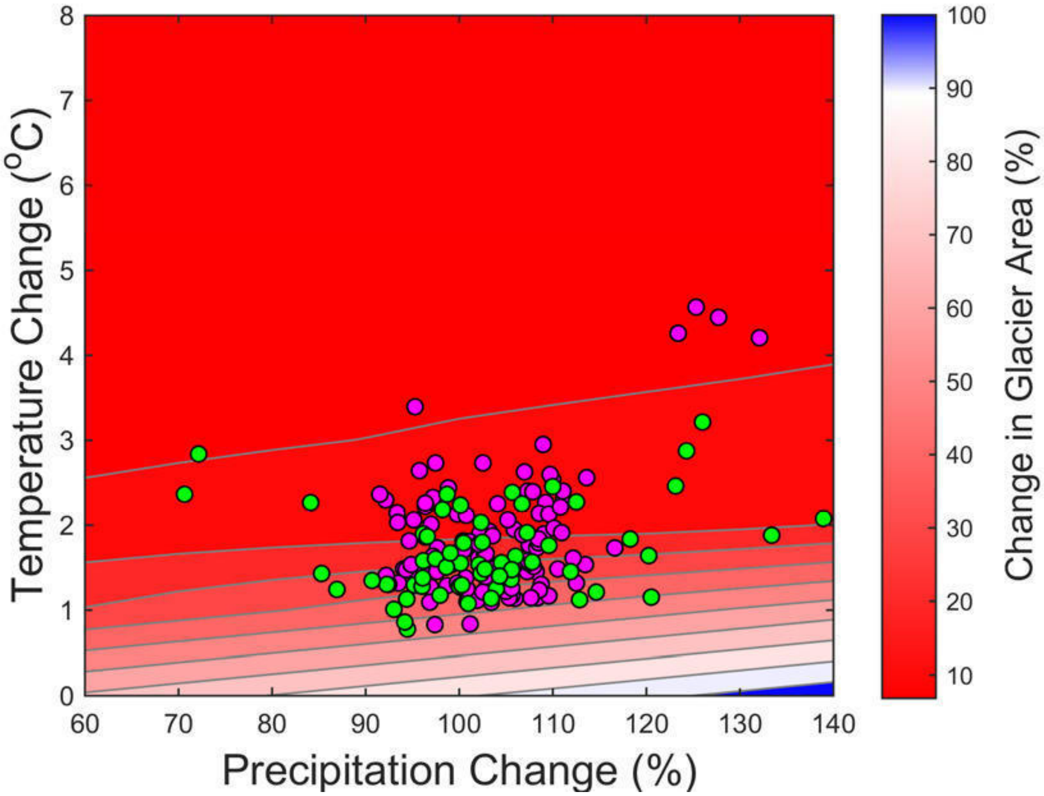


Figure 14. Change in glacier area (% of baseline/historic).

Figure 14 shows percentage change of glacier volume under a range of temperature and precipitation changes. The analysis is based on glacier coverage map data obtained from the Randolph Glacier Inventory version 3.2 (RGI 3.2, Pfeffer et al., 2014), and glacier volume was estimated using the multivariate glacier area-volume scaling relationships proposed by Grinsted (2013). Temperature is the dominated factor in the recession of the glacier area, as evidenced by the largely horizontal contour lines. Figure 14 explains the 3 degree inflection point in the streamflow response surfaces of Figure 12 and Figure 13. Because a 3 degree C temperature increase throughout the 30-year simulation reduces the glacier volume to less than 20% (relative to the initial volume), the remaining glacier area/volume is insufficient to continue to sustain streamflow at historic levels.

Climate projections from the CMIP 3 ensemble present a greater degree of uncertainty in precipitation, but less uncertainty (smaller spread) in forecasted temperature. The CMIP 5 ensemble shows mostly positive precipitation change (with less spread than CMIP3), and a temperature increase of approximately 2 degrees C. The result is substantial uncertainty in future streamflow conditions.

The climate change projections show a range of changes in precipitation from a 10% reduction in precipitation to a 20% increase in precipitation, with a few projections showing even larger increases. Projected temperature increases generally range from 1 to 3 degrees C. Because these projections have not been evaluated for their ability to reproduce the climate in this region, they cannot be interpreted as particularly meaningful. In addition, the ensemble of climate projections is a relatively arbitrary sampling (which is typical of climate modeling) and so caution must be exercised when interpreting the location of the circles.

It is worth noting that no clear risks to the project are identified within the range of the projections, except possibly in terms of larger high flow values in the future. The range of projections in Figure 13 almost all show increases or no change in streamflow. There does not appear to be a large risk associated with reductions in streamflow that would affect the economic performance of the project. Nonetheless, the question of reduced future streamflow is explored in greater detail later in this section.

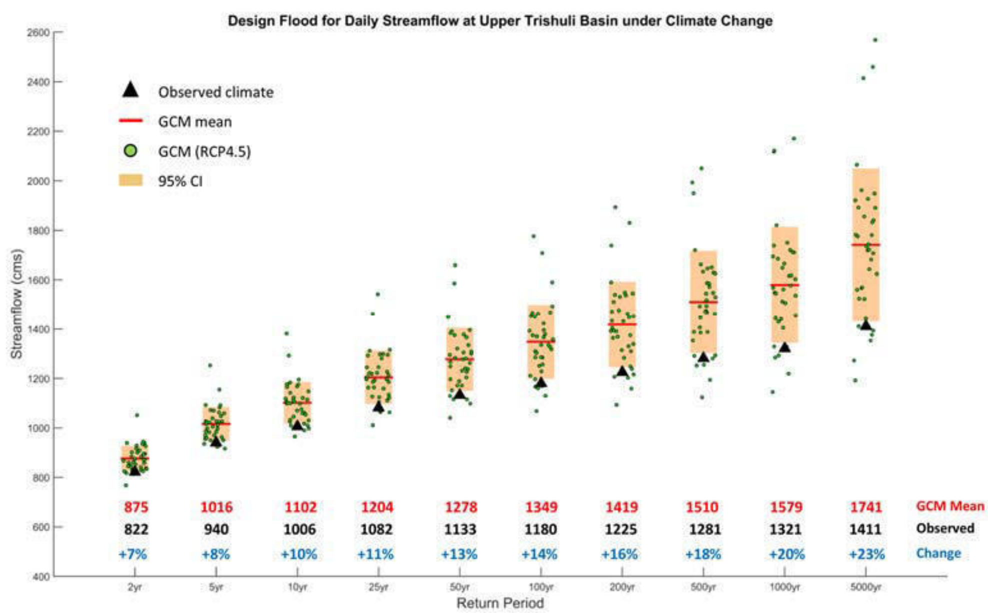
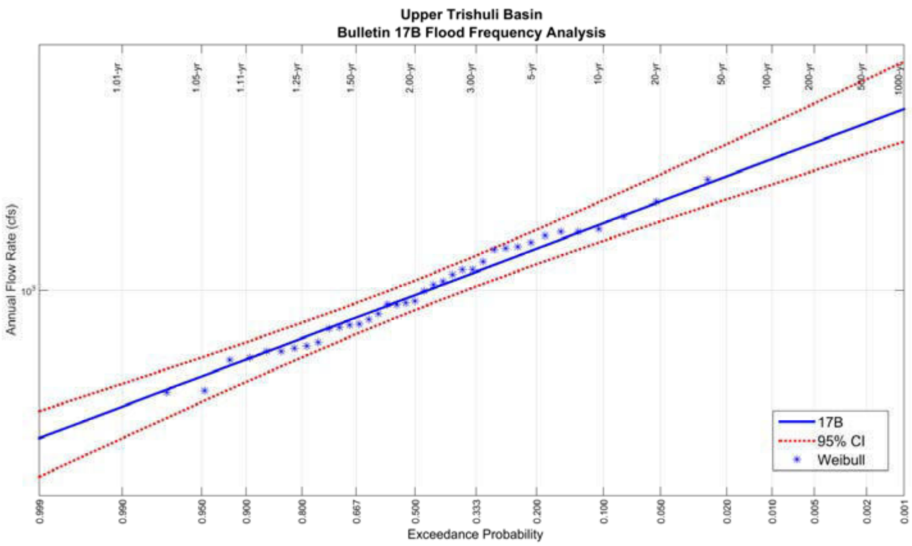


Figure 15. Design flood for daily streamflow under climate change.

The results of the streamflow response surfaces imply greater risk of increased streamflow in the 30-year lifetime of the hydropower facility (potentially with increased frequency and severity of floods that could damage the structure) than decreased streamflow. In order to examine these risks, we developed design flood estimates by fitting annual maximum streamflow series to the Log Pearson Type III distribution (the standard for the flood frequency analysis adopted by the US Army Corps Bulletin 17B). The black triangles in Figure 15 are modeling results, and therefore not a perfect reproduction of return periods for historical observations. The design flood estimates based on observed streamflow are provided in Figure 16. Due to an underestimation bias in the model representation of high flows (owing mostly to un-reconcilable data inadequacies), the absolute values in Figure 15 are not good indicators for evaluation. Nonetheless, the analysis of the percent change between modeled streamflow based on historical observations of climate and modeled streamflow based on projected future climate from GCMs is useful. The percentage change in the magnitude of flood increases approximately linearly with return periods of up to 500 years under CMIP 5 RCP 4.5. More extreme return periods (e.g., 1000, 5000 years) exhibit nonlinear responses relative to the historic. The conclusion to examination of Figures 15 and 16 is that the 5000-year flood may increase in magnitude by between 20% and 25%. This greater magnitude of the 5000-year flood has been accounted for in the engineering design, as explained in Chapter 5.



Return (year)	17B (cfs)
2.00	973
5.00	1256
10.00	1446
25.00	1690
50.00	1875
100.00	2062
200.00	2254
500.00	2517

Figure 16. Flood frequency analysis (after Bulletin 17B).

Returning to the analysis of potential changes to low season flow, Figure 17 shows hydrographs for increases in temperature of 2, 4, 6 degrees C compared to current conditions. As can be seen, the warming climate causes a significant increase in dry season streamflow, likely due to melting of glaciers and the immediate runoff of additional winter rainfall (that historically fell as snowfall).

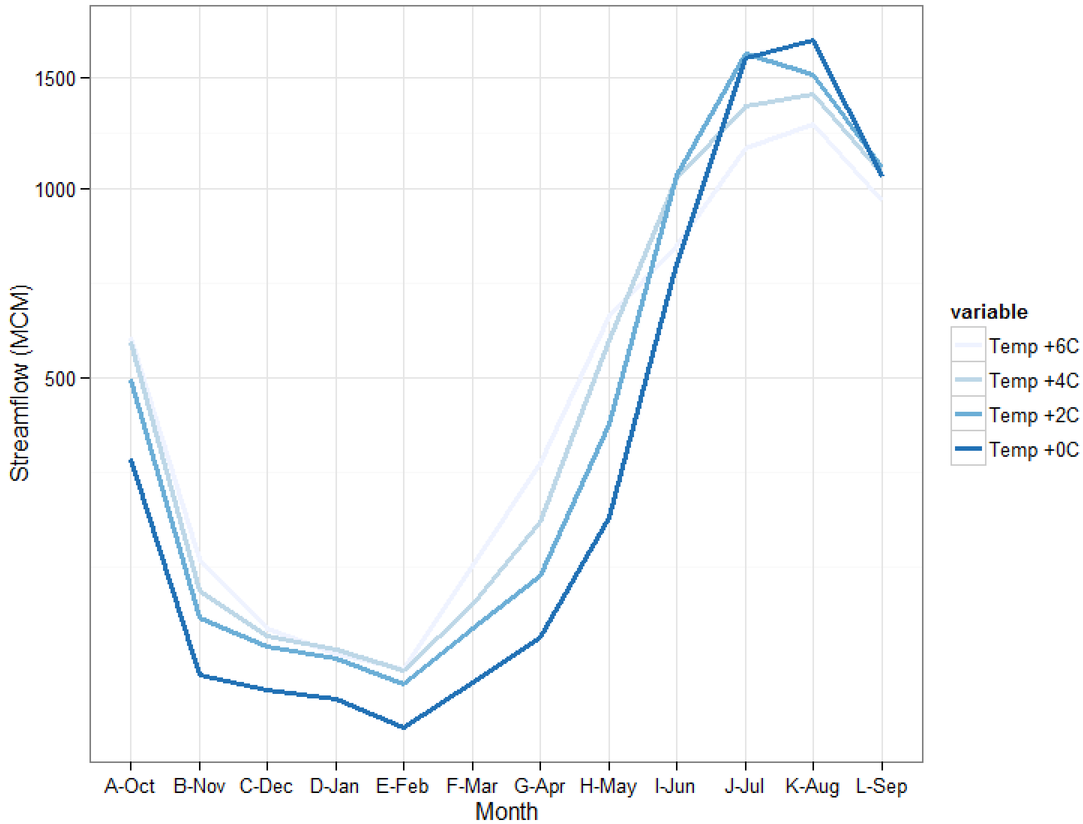


Figure 17. Shift in Seasonality due to climate change.

Figure 18 shows the number of days with flow less than the plant discharge (76 m^3/s) (a minimum requirement for generating hydropower in the full capacity) under various climate change conditions. The result indicates that there is a small chance to have increased number of days not meeting the plant discharge under the climate change conditions; i.e., precipitation decrease by 20% or more with temperature increase less than 2°C only causes increase in the number of days below 76 m^3/s. Both precipitation and temperature are factors that substantially influence the changes in this metric. Precipitation increase by 10% greatly reduce the number of days below 76 m^3/s, even with moderate increases in temperature (e.g., increases less than 1°C). According to the future projections of precipitation and temperature from both the CMIP 3 and 5 (purple and green dots in Figure 18, respectively), future scenarios that this system is safe from the threatening with more frequent occurrences of low flow becomes more persuasive. Since the average number of days from observed streamflow is about 160 days, the change corresponding to 12 %, which is the biggest change under GCM climate change scenario, indicates that the average number of days below 76 m^3/s throughout a year is approximately 20 days.

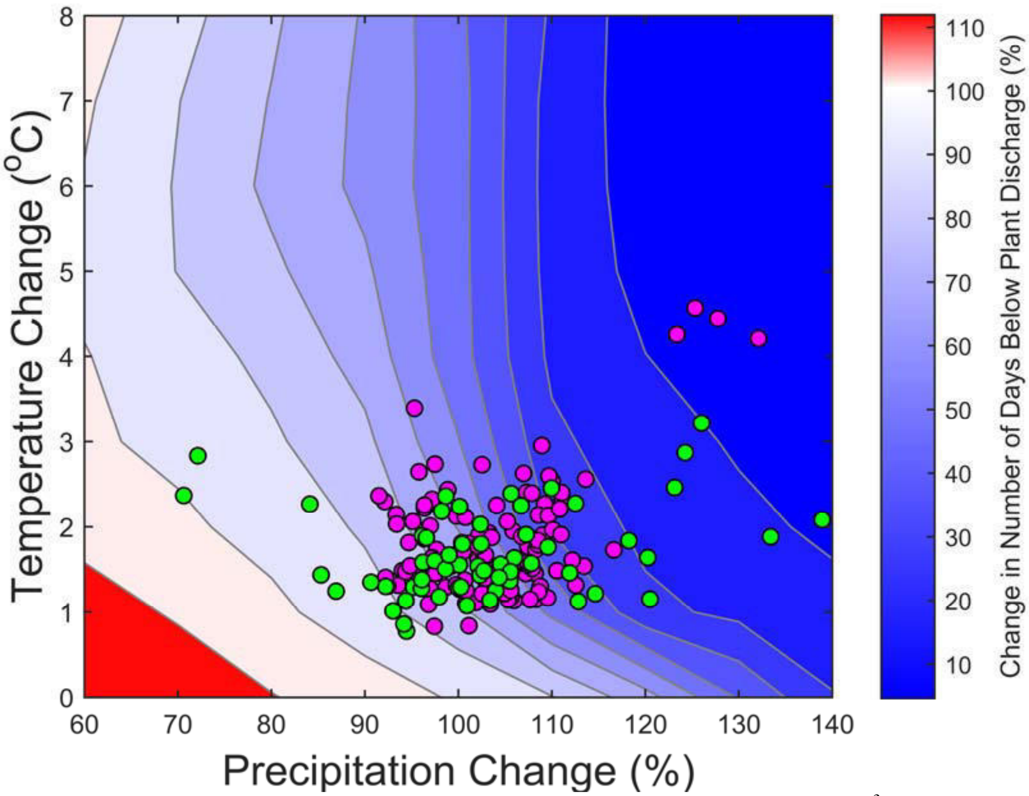


Figure 18 Percent change in number of days below the plant discharge (76 m^3/s).

For the concern of the environmental flow requirement, Figure 19 shows the results of a frequency analysis for annual minimum 7-day low flow using the Log Pearson Type III probability density function. The CMIP5 GCMs with RCP 4.5 emission scenario project an increase in the 7-day minimum flow in the future. Analysis of the percent change between modeled streamflow based on historical observations of climate and modeled streamflow based on projected future climate from GCMs is also made for the design 7-day low streamflow. The percentage change in the magnitude of design low flow increases approximately linearly with return periods of up to 5000 years under CMIP 5 RCP 4.5 scenarios.

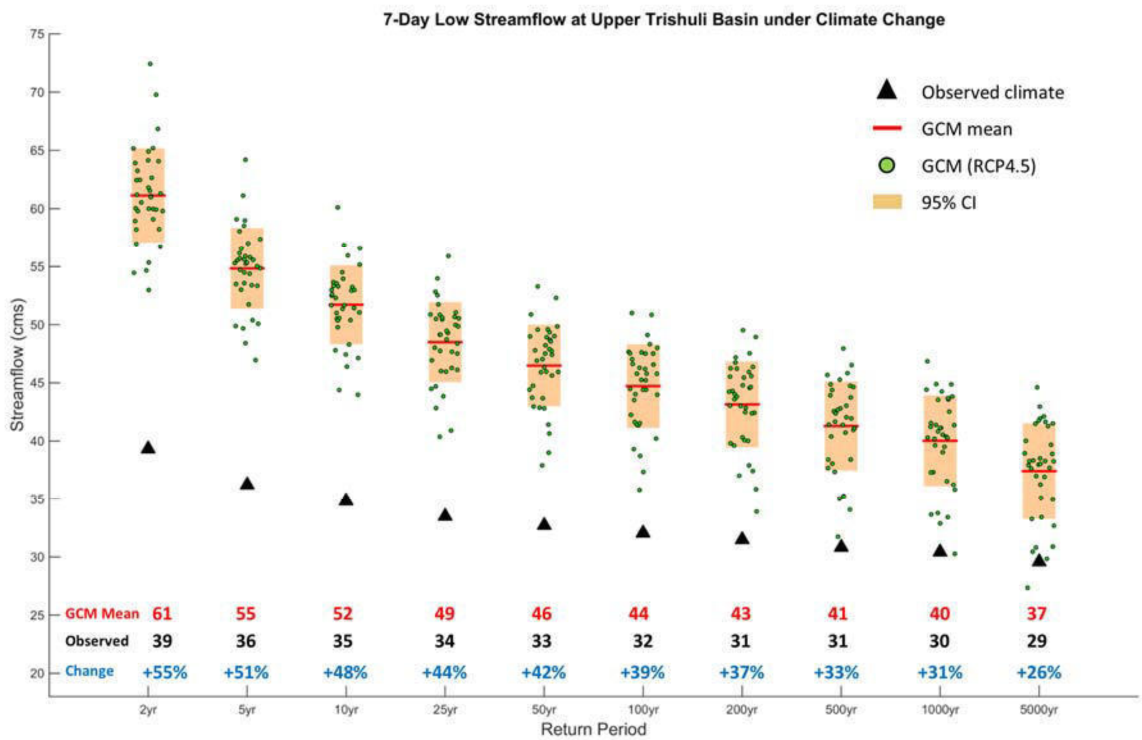


Figure 19 Frequency analysis with the Log-Pearson Type III for 7-day low streamflow at UT-1 basin under climate change.

These results, in combination with Figure 17, suggest that the level of concern associated with reductions in low season flow can be low.

3.2 Response of Hydropower Production

The hydropower response generally follows the streamflow response, as shown in Figure 20. With up to 2 degrees in warming, the high-value dry season electricity production is expected to increase from approximately 470 GWhr to approximately 550 GWhr. With 2 degrees of warming, total annual hydropower production increases from approximately 1515 GWhr to approximately 1640 GWhr, and with 3 degrees of warming the increase is to 1665 GWhr. The larger percent increase is in the dry season.

Care should be taken not to falsely associate colors in the 3 plots of Figure 20. Each color scheme is unique to the time period described, and relative to the respective mean.

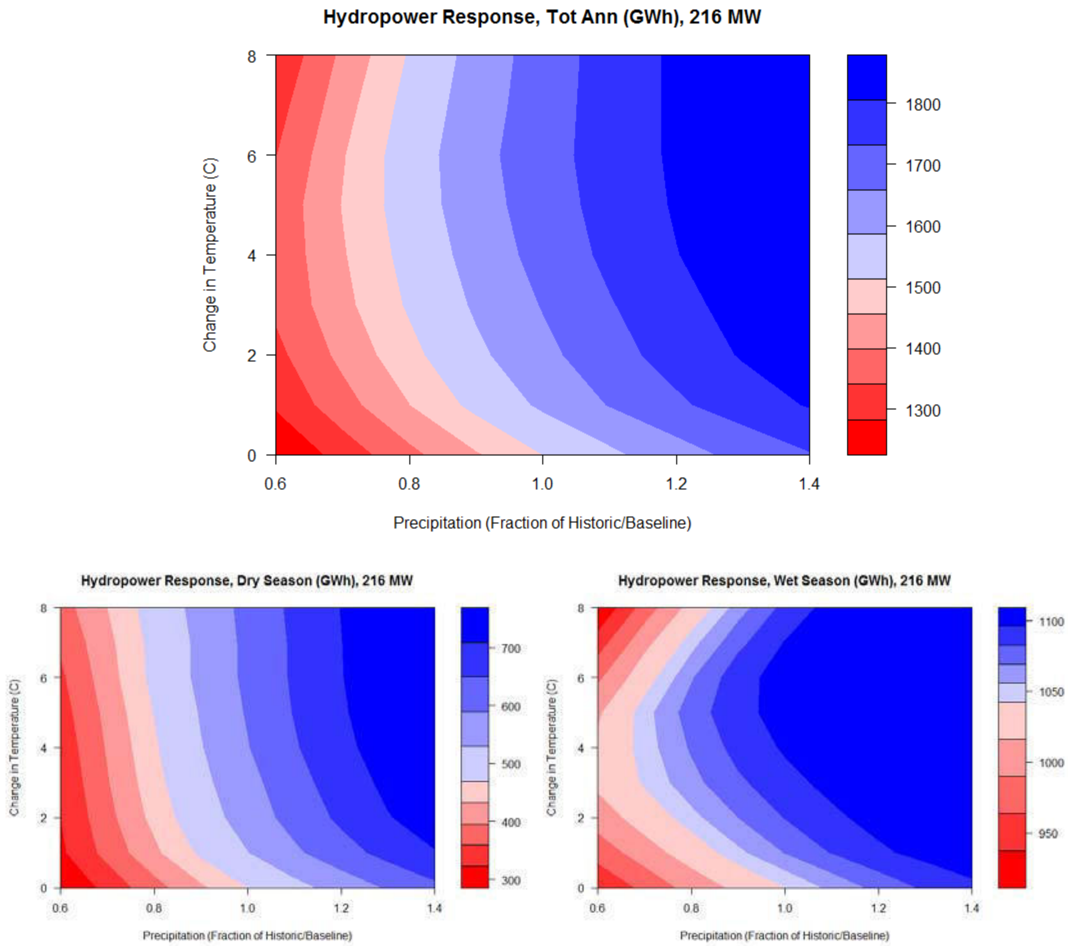


Figure 20 Hydropower generation climate response surface.

3.3 Response of Economic Performance

The range of possible economic performance under climate change is presented in Figure 21. Under baseline conditions (no change in precipitation or temperature), the NPV over the 30-year design lifetime of the project was estimated to be approximately $365M. Within the range of climate change explored, the NPV remained positive, increasing in “favorable” future climates to over $700M, and decreasing in “unfavorable” future climates to approximately $125M. More likely, with a 2 degree increase in temperature and a negligible change in mean annual precipitation, the increase in NPV would be to $475M. A 3 degree increase in temperature with negligible change in precipitation would result in an NPV of $500M.

The findings of Figure 21 are sensitive to assumptions regarding discount rate, capital/O&M cost, and electricity price, as summarized in Table 2. It is also assumed that all electricity produced is sold, meaning that we only model the supply-side of the energy markets. This assumption is contingent in large part on energy-trading agreements between India and Nepal, and should be approached with caution.

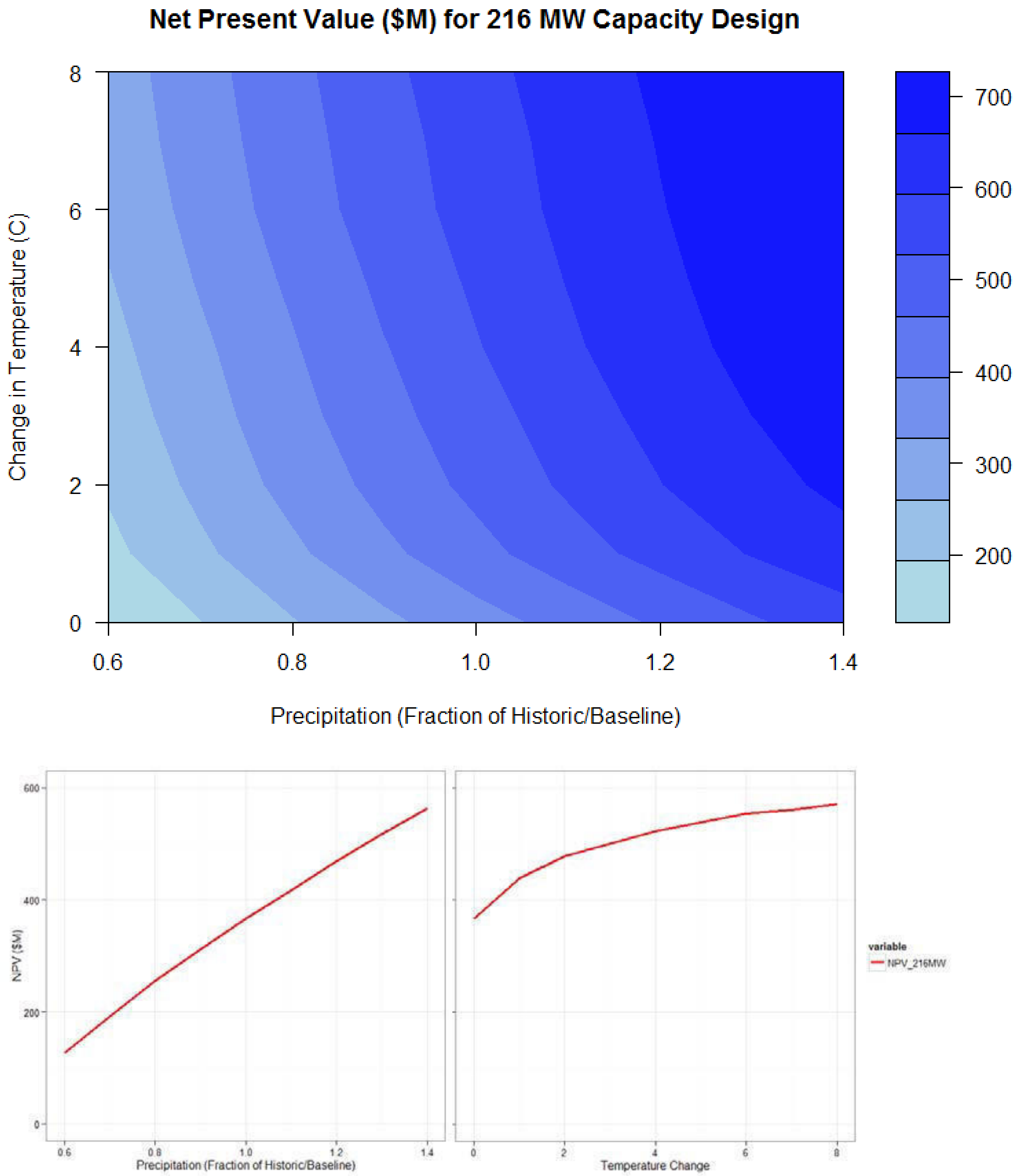


Figure 21 Range of possible economic performance of UT-1 hydropower plant under climate change.

3.4 Effect of Changes in Upstream Water Demand

One of the major concerns for a PROR dam is inflow changes due to upstream development. The changing volume and timing of upstream inflow caused by the upstream human development might affect the designed hydropower generation of the UT-1 project. In this section, we comment the effect of changing upstream water demand on streamflow.

The following figures show the current dominant land use/land cover (Figure 22a) and percentage of cropland inside the UT-1 basin (Figure 22b) according to FAO Global Land Cover SHARE database. Most of the crop lands are located downstream of the dam site and only 3.1% of the upstream land has crop activities. These figures indicate that under the current conditions, upstream water demand is not a major factor. Because domestic water use is relative small, no evidence of industrial water uses exist, and agricultural water uses is also understood to be limited based on the small percentage of cropland.

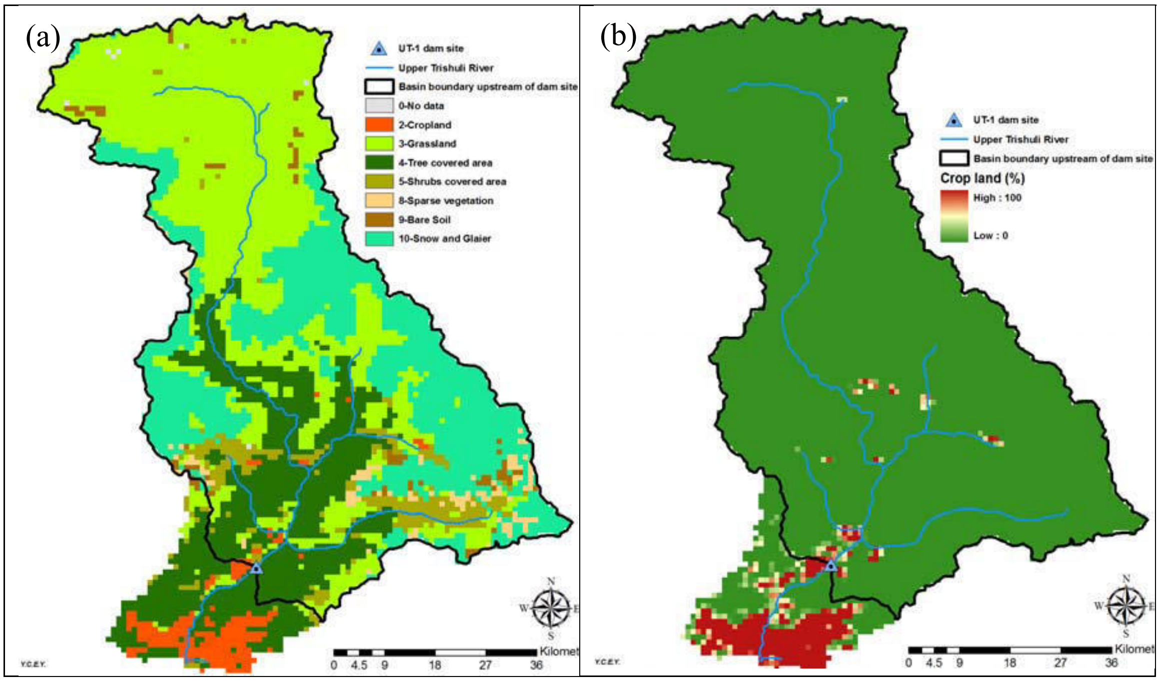


Figure 22 (a) Dominant land cover for the UT-1 basin; (b) Crop land percentage for the UT-1 project. Maps are created from FAO Global Land Cover SHARE database.

There is no evidence of any future industrial development upstream of the dam site. Due to the topography constraint, a dramatic population growth in the near future is unlikely. Therefore, no significant changes in industrial and domestic water uses are anticipated.

We evaluate potential agricultural water uses changes by comparing with other mountain agricultural developments plans in Nepal. High Value Agriculture Project in Hill and Mountain Areas (HVAP) is a joint project between Ministry of Agricultural Development and International Fund for Agricultural Development (IFAD) and focuses on the western districts of Nepal (e.g., Achham, Jumla, Salyan). The purpose of this project is to integrate the rural poor in high value agriculture and non-timber forestry products and the goal is to reduce poverty and vulnerability of people in the hill and mountain areas. Project components include: 1) making a marketing arrangement for producers and consumers; 2) providing service support for the market; and 3) providing technical support for the project management. Only a small part of the HVAP is to build infrastructure (road) to physically connect to a small number of more remote communities. No expansion of cropland has been proposed. We assume that if similar projects take place in the UT-1 basin, no significant change will be made on the current cropland. Therefore, no significant future agricultural water uses changes is projected in the UT-1 basin. The details of HVAP can be found on the official website http://www.hvap.gov.np/index.php.

In sum, based on our analysis, the effect of changing upstream water demand on UT-1 project is negligible.

3.5 Possible Disease Effects

According to a 2005 World Health Organization (WHO) report: "The effect of irrigation and large dams on the burden of malaria on global and regional scale" quantified the risk of public health caused by water project development and operation. Following the same concept, we evaluated the effect of additional surface (inundation) area causes by the weir construction and further link that with additional risk of the burden of malaria. According to Table 1.6-1 of the "Hydrologic Analysis" of the UT-1 design documents, we plotted the water level-surface area rating curve under natural condition and after weir construction. We also calculated the difference of surface area between these two curves in Figure 23. The maximal additional surface area that cause by weir was calculated to be 4,439 m^2 (when water level is 1243 meters above mean sea level, masl).

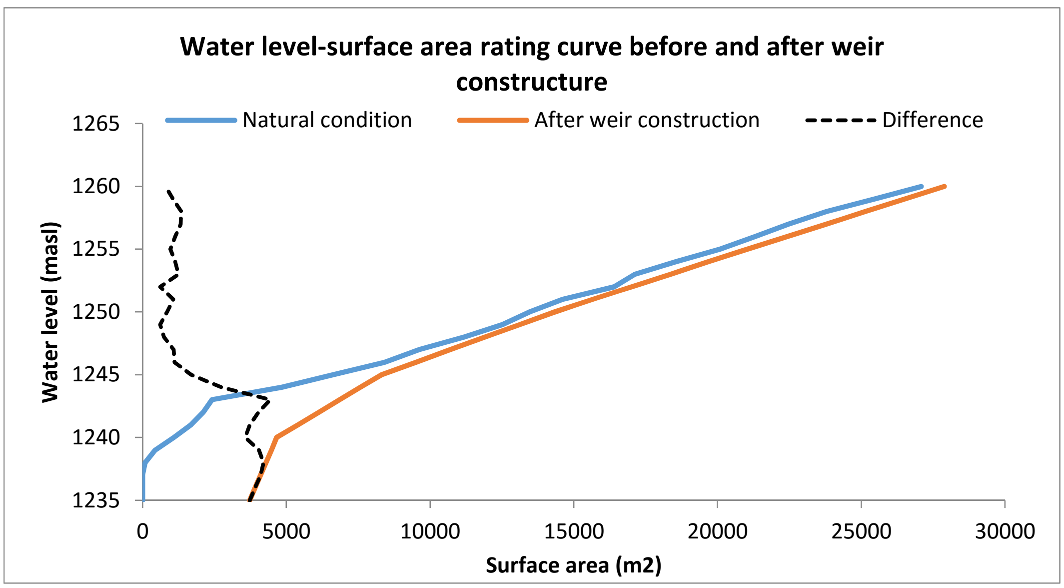


Figure 23 Rating curve for water level and surface area of the UT-1 project under current and after weir construction condition.

Following the WHO 2005 report, we estimated mosquitoes' flight range change due to the weir construction. Figure 24 shows how the estimation was made. In Figure 24, the green polygon is the original surface area under natural condition and the blue polygon is the additional surface area causes by the weir. In reality, this blue part has an irregular shape and is difficult to estimate the width of it without the original digital elevation map (DEM) data used by the design document. In this study, we followed the WHO 2005 report and used a rectangular shape as a proxy. The width of the weir is 30.85 m and under the extreme condition the longest length of the blue part is 143.9 m (4,439/30.85). According to Boyd

(1949), the typical fight range of mosquitoes is 2,000 m. So the additional surface area cause by the weir will only increase maximal 7% (143.9/2,000) of mosquitoes' flight range. Given the sparse population located in this range, we conclude the possible disease risk cause by the UT-1 project is low.

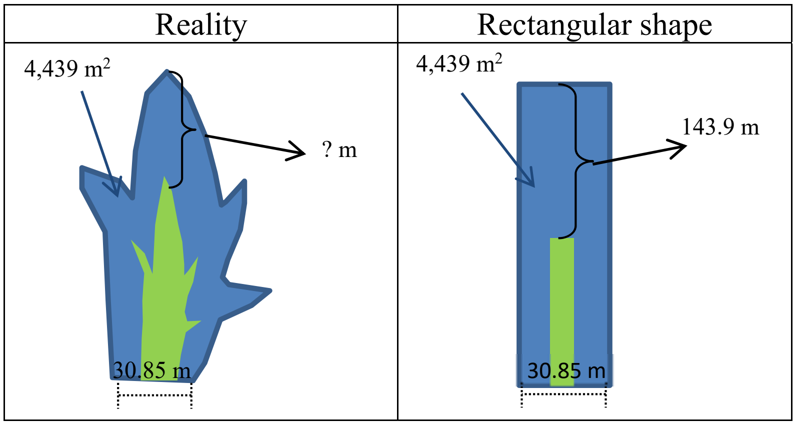


Figure 24 Estimation of area at risk of malaria near dam.

3.6 Structural Stability and Dam Break

A comprehensive analysis of dam structural stability and dam safety is beyond the scope of this climate change analysis, as the topic involves structural engineering, geology and seismology. In this study, we only evaluate the dam safety issue from the hydrological perspective by comparing designed capacity of weir and the peak flow under climate change impact.

According to the UT-1 dam design documents, the capacity of weir discharges is 3,563 m^3/s (corresponding to return period 5,000 years) and 3,276 m^3/s (corresponding to return period 2,000 years) when one gate malfunctions. We compare these two values with the frequency analysis presented in a previous section and use Figure 25 to explain the result. In Figure 25, the black triangle is the result from long-term historical streamflow data. The values are the same as Table 1.3.1-5 in the "Hydrologic Analysis" of the UT-1 project design document. Since we used two probability distributions, Gumbel and Log Pearson Type III in our frequency analysis under climate change, we have two changing percentage values for each return period. We used these two changing percentage values, multiplied them by the historical values based on the frequency analysis (black triangles) and plotted them as orange box in Figure 25. Two horizontal lines were added to represent design capacities for 3,563 m^3/s (red) and 3,276 m^3/s (purple).

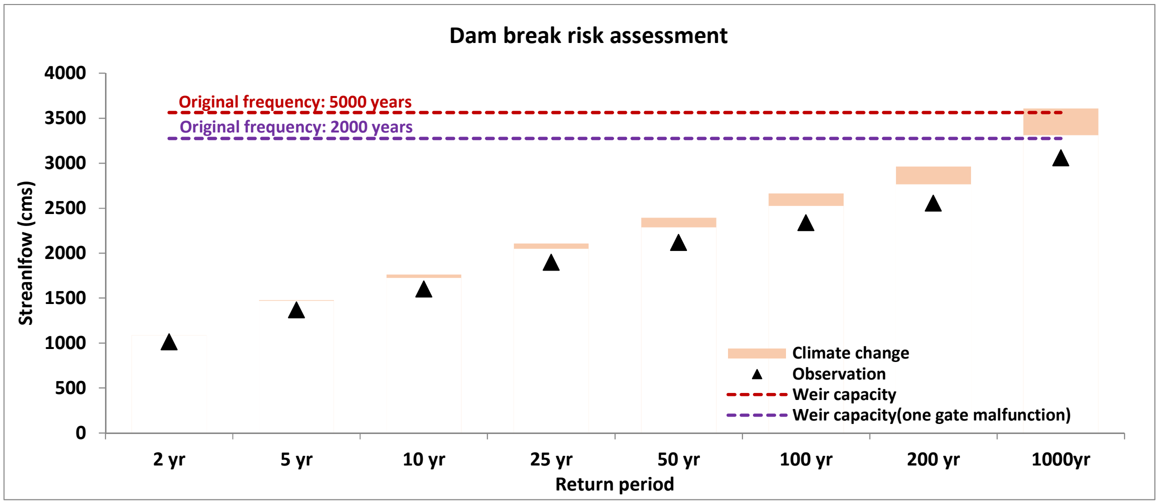


Figure 25 Compare weir designed capacity of UT-1 project with flood frequency under climate change impact.

The impact of climate change is expected to increase streamflow volume for a given return period or reduce return period for a given streamflow volume. For example, under the historical climate, 2,300 m^3/s is a 100-year flood. The same volume of streamflow becomes a 50-year flood under climate change impact. Therefore, climate change impact does post a threat on weir capacity design. However, the original design can be seen as "overcapacity" since it uses 5,000 and 2,000 year return period as design standard. This is addressed in Chapter 5.

4. Possible Adaptation to Address Climate Risks

The previous section discussed some of the vulnerabilities that were identified during the preliminary analysis. The next step in the analysis is the assessment of the risks associated with those vulnerabilities, and the consideration of possible adaptations to reduce risks. Risks are estimated by assigning probabilities to the conditions that cause vulnerabilities. For each of the risk scenarios defined above, a probability estimate is assigned to that scenario based on available information. Since the probabilities are necessarily subjective, the term "level of concern" is used to clarify the purpose of the probabilities. Level of concern is estimated based on three factors: 1) theoretical basis for the climate change (i.e. atmospheric science); 2) observations of the climate change (i.e. historical trend); and 3) modeling projections of the climate change (i.e., GCM results). The level of concern is higher when the three factors are in agreement regarding a particular change. An example is warming temperatures, where there is a clear theoretical basis for why temperatures are warming, the observed record shows temperatures increasing, and climate change projections indicate further increases. Probability estimates may also be applied to other uncertain factors if reasonable means of estimating them are available.

Table 3 summarizes the results of the preliminary risk assessment. In general, the risks of climate change to UT-1 can be described as low. The project is designed conservatively in terms of the expected flows needed for hydroelectricity generation. The sedimentation basin, weir and spillway, which may be considered the most potentially vulnerable aspects of the design, have been designed conservatively. The climate stress test analysis revealed that low flows are largely insensitive to plausible changes in climate.

Table 3 Preliminary assessment of risks.

Risk	Cause of Concern	Level of Concern
Flood	• Climate change may cause extreme streamflow to increase in volume or frequency • Climate stress test indicates that climate warming could increase extreme design flows by about 20% • Spillway is designed for 5000 year flood which is quite conservative • Design based on Gumbel extreme value distribution; other distributions would yield a much higher flood magnitude for the 5000 year flood (e.g., log Pearson Type III) • Increasing weir/spillway capacity may be considered	Low
Sedimentation	• Climate change may increase sedimentation rates due to increases in the intensity of precipitation • Sedimentation rates are already high • Sedimentation basin has been designed quite conservatively • May consider operational approaches to managing sedimentation events	Low
Missed opportunity	• Failure to capitalize (regret) on potentially increasing flows by not increasing the capacity of the headworks and turbines	Not modeled at this stage
Reduced low flow	• Climate change may cause a decrease in streamflow during the low flow season • Low flow season streamflow is vital to energy production needs in Nepal • Climate stress test revealed that low flow season flows are largely insensitive to climate warming • Precipitation changes may cause increase in low season flows • No clear indication that low flows are a concern	Very Low
Structural stability and dam break	• To be determined	Low, based only on risk of increased precipitation-based flood
Disease	• To be determined	Low, based on mosquito analysis

The potential for climate change to effect high flows deserved close attention, and possible adaptation. Increasing precipitation and increasing intensity of precipitation are both generally consistent with the expectations for a warming climate. Both could contribute to increases in flood flows and increases in sedimentation. Thus the adaptation analysis focused on addressing these possible concerns.

5. Proposed Adaptation Subsidy

The weir and spillway is currently designed for the 5000 year recurrence interval flood event. The spillway is designed to safely pass flows that exceed the capacity of the headworks and weir. This is a conservative design and exceeds the design capacity of the downstream structure. There is a great deal of uncertainty associated with estimating the level of a 5000 year event, since such events are very rare, an in fact, never yet experienced in the flow record. As a result, the flow level associated with such a design event is sensitive to the extreme value distribution (i.e., statistical model) used to estimate the event. The analysis of the hydrologic contractor showed a range of 3,428 cm^3/s to 5,411 m^3/s for the 5000 year event based on the choice of extreme value distribution. The selected design event was 3,563 m^3/s, which is the low end of the aforementioned range. The largest design flow value was based on the log Pearson Type III extreme value distribution, which is the distribution preferred by the US Army Corps of Engineers.

The sedimentation basin performs the role of reducing streamflow velocity such that suspended solids can settle to the bottom in the basin rather than in other locations which would reduce the capacity of the headworks or damage turbines. The sedimentation design is quite conservative and is likely to handle possible increased sedimentation due to climate change. Nonetheless, low cost adaptation may be considered to address the large degree of uncertainty associated with possible future climate changes.

Table 4 summarizes elements of the proposed design already accounting for climate change above and beyond “business as usual” safety factors. The primary functions of the climate-robust design elements are river diversion, design modifications to account for the increased likelihood of glacier lake outburst floods (GLOFs) in a warmer future, and an extra-capacity de-sanding basin to account for the risk of increased turbidity due to greater precipitation variability in the future. The total value of the climate-robust design elements is approximately $55M, and is eligible for blended finance under IFC regulations. Table 4 is preliminary, and represents no promises of the IFC at this stage.

Table 4 Blended finance for UT-1 investments in climate change robustness.

	Component	Units	Event	Cost with provision for climate change	Cost business as usual	Diff.	Remarks
1	River diversion works (The design flood proposed for the diversion scheme is the 2 year return period wet season event with a magnitude of 1,012 m3/s.)			18,900,000			
2	Design flood for weir 5,000 year (3,563 m3/sec) to withstand GLOF*		GLOF	21,300,000			
3	Dam foundation to cope with the 5,000 year flood to withstand GLOF		GLOF				
4	Large gates to release extreme discharges (10,000 year ?) and sediments; A gated concrete intake weir containing 3 spillway bays; 3 radial gates 11.0 m wide x 16.5 m high						1 extra gate supplied for safety factor
5	Addition of Gravel Trap, Tranquilizing basin & Undersluice						
6	Desanding basins (The concentration varies from a minimum of 35 mg/l in January to a maximum in July of 1798 mg/l.) **			14,300,000			
7	Intake designed to operate with the reservoir completely filled with sediments, meaning that even with a sediment load significantly larger than anticipated the intake should be able to cointinue to operate as designed						
8	An access is provided to facilitate heavy equipment access to the area of the intake for clean out during the low-flow period, in case of severe sediment loading ***						
9	Cost of hydraulic model tests to address climate change concerns			250,000	0		
10	Cost of hiring Cloudwater to conduct climate change analysis	LS	Both monsoon and low flows	150,000	0		
11	Real time sediment monitoring			150,000	0		
12	Early warning systems	LS					

13	Underground powerhouse avoiding the risks of a major GLOF flooding vs. Surface powerhouse			
14	Turbines coating			
15	Provide extra spillway capacity on the left bank			to be modeled and costed
16	Generation foregone due to flushing based on real time sediment monitoring	GWh	Monsoon sediments reaching above 5,000 ppm	

*In business as usual the option could have been 3,276 m^3/s (2,000 year frequency) m^3/s (2,000 year frequency)
**Basin length to exclude particles less than 0.2 mm from passing through the turbines
***The bridge over the weir which supports the spillway gantry crane and as a maintenance access for the weir has been designed as precast concrete box elements tied together transversally by post-tensioned tendons.

An optimization exercise was carried out by the designers to determine the size and the number of the flushing channel/culverts and the gradient of the flushing tunnel. The flushing plan adopted for the Project will be to close off one desander at a time leaving two units operating. It has been estimated that the loss of generation time will be 5% annually. The flushing cycles for the desander vary according to the month of the year. For January to April and November and December flushing will take place once per month for the remaining months the following frequencies have been estimated: May – 4 times; June- 9 times; July 19 times; August – 13 times; September – 8 times; October – 3 times.

6. Conclusions and Recommendations

This report has analyzed in depth the climate change related risks to the UT-1 hydropower project and concluded the associated risks to the structure and performance of the proposed UT-1 hydropower facility to be low, as summarized in Chapter 4. Conclusions are limited by the available data on historical climate in the basin and region, and in statements regarding likelihood, the conclusions are limited by the quality of the best available GCM projections. Economic performance projections are further subject to uncertainties in electricity markets, discount rates, O&M costs, and transmission infrastructure, among other things. Chapter 5 has presented climate-robust design modifications already incorporated into the UT-1 proposal. The design modifications presented in Chapter 5 address most of the concerns raised in Chapter 4, and as such are eligible for blended financing by the IFC.

Appendix: Cost Estimate for Items 1, 2 and 3 by Hydro Lab, Nepal

Item 1: Real Time Sediment Monitoring System
Item 2: Stream-flow Monitoring and Early Warning System
Item 3: Sediment guided operation system

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Appendix G
Fish Ladder Expert Review

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Margenex International

January 16, 2018

Dr. Leeanne Alonso
4618 Duncan Drive
Annandale, VA 22003

Re: Fish ladder for Upper Trishuli-1 HPP

Dear Dr. Alonso:

Thank you for the opportunity to review the report entitled "Principles for Design of Fish ladder for UT-1 HPP" by Halvard Kaasa, a civil engineer and fish scientist for Sweco Norway AS. I have reviewed this report in detail, with focus on the fish ladder design.

This report gives comments and recommendations for technical solutions to keep river connectivity when the Upper Trishuli-1 Hydropower project (UT-1) is in operation. The dominant species in the UT-1 area of Trishuli River is the Asala (*Shizothorax richardsonii*), a species of Snow Trout that migrates upstream and downstream for breeding, feeding and rearing purposes on a seasonal basis. The total height of the fish ladder will be approximately 30 m. The exact height will be decided when the design of the fish ladder entrance pool is settled. To meet the requirements for migration of Snow Trout, the total number of pools will be close to 100.

The report provides adequate details of the conditions for the fish ladder design, considering the characteristics of the target fish species, flows through the fish ladder, and available space in the geophysical setting. The report lays out details of the crucial lower entrance of the ladder and explains, with appropriate figures, the design of each of the ten pools at the lower end, as well at the set up for the water of attraction. The latter is key to enticing fish to enter the facility.

Regarding the design of the proposed fish ladder, I like the alternating weir notches in each of the pools. The maximum water level drop of just under 12 inches, coupled with the 8 inch square drain openings near the bottom of each pool, should allow adequate upstream passage of adult Snow Trout during low flows of March and April. In my experience in Washington State, a very conservative weir drop is 9 inches is desired to accommodate small salmonids (mainly Cutthroat Trout, which would be analogous to adult Snow Trout, in this case), but most Pacific NW professionals would say that 12 inches should be satisfactory. I am also fine with the lower entrance pool and upper exit pool schemes.

The report provides a reasoned description of upstream fish migration challenges not related to the proposed fish ladder, and notes considerations for downstream fish migration, including current in the intake pond, the pool downstream of the weir, and tunnel entrapment. It also outlines the types of data that should be obtained in order to properly manage the fish ladder.

My main concerns mirror what has been stated in the report:

- The conditions in the pool outside the fish ladder entrance is crucial for the functionality of the fish ladder; and

- The water level in the pool of the fish ladder entrance will, by existing design, fluctuate between 1229.1 m (5 m^3/s) to 1,231.5 m (154.4 m^3/s). Fluctuations of up to 2.4 m (8.9 ft) might lead to challenges concerning fish migration.

In conclusion, it is my opinion that there is reasonable likelihood this fish ladder will function to meet the project objective of allowing Asala connectivity above and below the hydropower project, based on the approach described in the Sweco Norway AS report.

I would like to see the details of how they plan to carry out monitoring to quantify fish use of the ladder, such as conventional tagging, sonic tagging or observations. If the latter, I recommend two to four fish viewing windows, evenly spaced along the ladder, for quantifying upstream migration.

I look forward to working with you on this project in the future. Please contact me if you have any questions.

Sincerely,

Margenex International

S/S Mark G. Pedersen

Mark G. Pedersen, M.S. FP-C.
President
and Senior Fisheries Consultant to the IFC