HYDROPOWER DEVELOPMENT ON GLACIAL LAKES

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ABSTRACT

As much as 69% of the world's fresh water is stored in glaciers around the world. As these glaciers begin to melt and recede, they will leave behind a significant storage volume of water at high elevations. This combination of water storage and elevation presents unique and relatively untapped possibilities for hydropower development. Early estimates put the potentially developable hydropower from these glacial basins at over 1300 TW-h per year. While hydroelectric development of these lakes might avoid some of the typical perceived environmental challenges associated with hydropower, such as the flooding large amounts of otherwise useable land, there are also significant hazards that must be addressed before development can be considered. Some of these issues include access, harsh climatic conditions, transmission constraints, the use of un-engineered natural moraine dams as part, or all, of the water retention strategy and dealing with all of the typical hazards that confront hydroelectric developments in mountainous regions including flash flooding, landslides, debris flows and the reservoir sedimentation.

This paper discusses some of these issues and explores the potential that these developments have to reduce the greenhouse gas emissions regionally throughout the world to help address the commitments that were made as part of the Paris Climate Accord.

1. INTRODUCTION

As the planet continues to adapt to the "new normal" being created by a changing climate, many aspects of the hydrologic cycle, such as an increasing the amount of evapotranspiration, increased convectional storm activity, shorter, warmer winters leading to decreased snow accumulations, the thawing of glaciers and permafrost and the type and frequency of natural hazards, will need to be accounted for by the hydroelectric power industry. Glacial ablation has and will result in a reduction of the total flows available for hydroelectric power generation and a change in the distribution of these flows from the summer months, when they are often most needed, to later in the year. responding to changing precipitation patterns.The negative aspects of climate change are well documented in the literature. However, these changes can also provide opportunities. In the case of glacial lakes, the receding glaciers have the potential to provide new source of clean water for irrigation and hydroelectric power that, properly managed, can mitigate some of the negative impacts.

This paper discusses some of these issues and explores the potential that these developments have to reduce the greenhouse gas emissions regionally throughout the world to help address the commitments that were made as part of the Paris Climate Accord.

2. CLIMATE CHANGRE AND EXPANDING GLACIAL LAKES

Glaciers act as natural reservoirs, storing water in a frozen state and modifyingstreamflow's, typically releasing most runoff during the warmest, driest periods when all other sources of water are at a minimum ()making glacier runoff a valuable water resource for hydropower. In Sweden, for example, Stenborg, 1970 noted that glacier runoff peaks at the height of the melt season July and August in the Northern Hemisphere while runoff from non-glacier alpine basins typically peaks in May and June (Figure 1). Unlike non-glacier runoff, glacier runoff correlates better with temperature than precipitation, due to the dominant role of glacier melt compared to precipitation in summer runoff from glacierized basins. This is also the reason for the strong diurnal nature of glacier runoff.

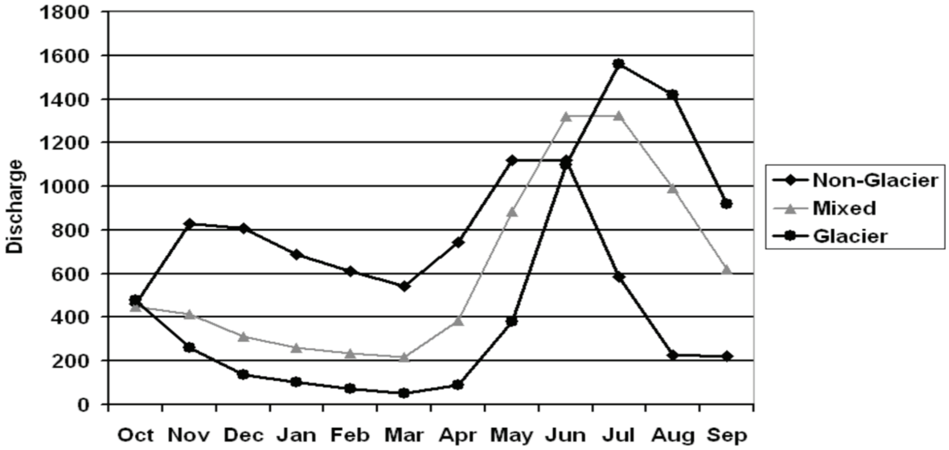

Figure 1 : Comparison of glacial and non-glacial runoff conditions in 1957 at Mikkaglaciären in northern Sweden

Although glaciers have and will continue to recede as a result of climate change (Figure 2), at any given time, the total long-term runoff flows do not necessarily increase nor decrease as a result of a reduction in glacial meltwaterdue to the fact that the total runoff over a period of several years is determined largely by annual precipitation.

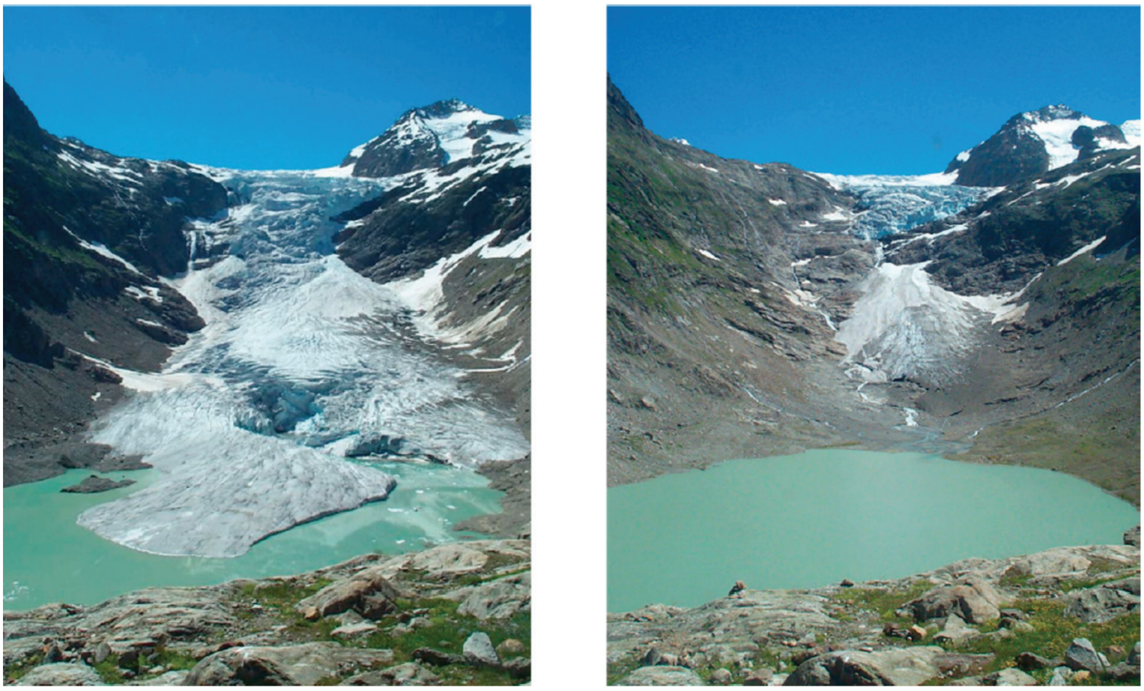

Figure 2 : New lake at the tongue of Trift Glacier on 30 June 2004 (left) and 3 July 2014 (right), illustrating the fast glacier retreat encountered in the Swiss periglacial environment.

In fact, there are two changes that occur as a result of the effects of climate change. The initial response is an increase in the glacier melt rate as has been observed in mountainous regions around the world (Andreassen et. al., 2005; Braun et. al., 2000; Zhang et. al., 2008)). Eventually the decline in the extent of the glacier culminates in a reduction decrease in glacier runoff. Typically, this occurs when there is a decline of more than 20% in glacier area(Pelto, 2008; Stahl and Moore, 2006). In the long run, glacier retreat has the impact of reducing summer flows with a corresponding increase in winter and spring flows consistent to periods when water supply is already high in most alpine regions. An example of the potential impacts of glacial recession on the available water resource is presented in Figure 3.

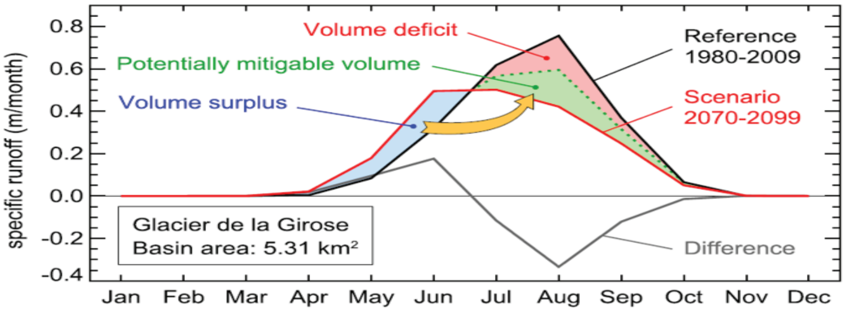

Figure 3 : Mitigating the impacts of glacial recession through water management at Glacier de la Girose in France (Farinotti, 2016).

As noted by The Swiss National Science Foundation, 2012;

"Glaciers store water and transfer winter precipitation into summer runoff. Once they have disappeared, we will need to manage these new reservoirs, which will take over this water storage role."

3. EXAMPLES OF HYDROELECTRIC POWER GENERATION FROM GLACIAL RUNOFF

The use of glacial runoff for hydropower generation in general, and glacial lakes in particular, is not new. Countries around the world have long used glacial runoff as a reliable source of water and glacial lakes to store this water.

3.1 South America

A number of South American countries are highly dependent upon glaciers and glacial runoff for energy production. In the Andes region, hydropower supplies 81% of Peru's electricity, 73% of Colombia's, 72% of Ecuador's, and 50% of Bolivia's, in each country glaciers contribute a significant portion of this runoff. In the Cordillera Blanca, Peru glacial cover has been shrinking since the 70's, decreasing by 15% over a 25-year span. In the Rio Santa Basin of Peru glacier runoff comprises 35% of the total runoff (Vergara et. al., 2008).

In Peru, in 1941, a Glacial Lake Outburst Flood (GLOF) inundated the town of Huaraz in the Cordillera Blanca, killing over 5,000 people (Reynolds, 1992). Since then, the Peruvian government, and other associated agencies, have grappled with the hazards presented glacial lakes. One solution has been to drain the lakes. However, the Peruvian Government also recognized that the lakes themselves represented a significant resource. Over the decades that have followed since 1941, the Peruvian authorities have developed a strategy of both lowering some lake levels to reduce the hazard (Portocarrero, 2014) and managing the lakes, using the stored water for hydropower generation. For example, Laguna Parón(Figure 4) is a glacial lake that lies about 17 km to the east of Caraz at an elevation of about 4,000m. The lake is contained by the 250 m high Hatunraj moraine. Since 1958, hydroelectric power has been generated downstream of the lake at the Cañón del Pato hydroelectric scheme. Generation was enabled using the glacial lake through the construction of a retaining dam designed to reduce the potential for a GLOF and a tunnel, designed to release the lake's waters at about one meter per second (m/s) that provided reliable flow and allowed the lake level to be lowered in a controlled fashion by about 20 m (Reynolds, 1992). Over the years, there has been a 50% glacier runoff reduction that has resulted in a decrease in energy production from about 1540 gigawatt-hours to 1250 gigawatt-hours. The trend is expected to continue with an expected decline to 970 gigawatt-hours for a 100% glacier loss (Vergara, 2008). Clearly, the planning of hydropower facilities such as these must consider these realities (https://glaciers.nichols.edu/glacier-runoff-hydropower/)

Figure 4 : Laguna Parón, Peru (Reynolds, 2018)

3.2 Asia

In India, about 50% of the countries hydroelectric power is generated by streams draining Himalayan glaciers. Climate change is impacting the availability of water from these sources. For example, the Gangotri Glacier that forms the headwater of the Bhagirathi river with an area of 286 km^2, provides flows of up to 190 m^3/second (Singh et. al., 2006) but has retreated 1 km in the last 30 years which will change the amount and timing of the available flow. Similarly, in Pakistan, about 45% of hydropower along the Indus River is supplied by large glaciers of the Karokoram Range. Two of the largest, the Biafo and Baltura glaciers are retreating rapidlywhich has been reflected in a marked decline in flow.

In Tajikistan there are more than 8,000 glaciers with a combined area of 8.5 thousand sq. km. These glaciers supply most of the rivers in country. On Vakhsh river, for example, there are five of the largest facilities in Central Asia including the 3015 MW Nurek hydroelectric power stationwhich supplies almost 70% of the countries hydroelectric power. The facility is supplied by almost 13 km^3 of glacial meltwater during the peak summer months. (Normatov and Petrov, 2006).

3.3 Europe

In Europe, the total runoff yield from presently glacierized surfaces is expected to increase by about 0.25 to 1,8 km^3 in the period of 2010–2039 and subsequently decrease to between about 0.1 to 1.3 km^{3}in the period of 2070–2099 (Farinotti, 2019).

In Switzerland, glacial runoff supplies about 50% of the countries hydroelectric power (Paul, 2007). However, satellite observation of a sample of 270 glaciers indicates that there has been a 20% area loss in the period between 1973 and 1998, a trend that can be expected to accelerate due to the impacts of climate change. Water management has been identified as one of the solutions to maintain power flows. For example, the Grand Dixence Dam ,situated on the Dixence River, collects glacier meltwater during the summer months using a system of water supply tunnels over 100 km long that help to re-distribute the available flows. The Swiss Federal Institute for Forest, Snow and Landscape Research explored the potential for water management and the hydropower potential of areas that are expected to become ice-free during the course of this century. For the roughly 185,000 sites studied, they predicted a theoretical maximum storage and hydropower potential between 600 and 1100 km^3 and 800 1900 terawatt-hours per year could be available, although they cautioned that only part of it practicably exploitable.

Many of Austria's larger hydroelectric facilities are supplied by glacier meltwater. For example, the 700 MW Kaprun power station receives 60% of its water supply is from Pasteze Glacier by means of a 12 km long tunnel. This glacier has been reported to be retreating at a rate of 51 m/yrwhich, without adequate management measures, will reduce the available melt season runoff and hydroelectric power generation potential.

In Norway, about 15 percent of the hydroelectric power flows are derived from glacier melt with up to 80%, occurring during the summer months. In northern Norway, the 370 km^2 Svartisen glacier, and a number of smaller glaciers, provide about 50% of the flows utilized by the 600 MW Svartisen hydropower plant. The plant receives water from a number of rivers and streams west of the Svartisen glacier by means of a network consisting of a total of 100 kilometers of tunnels and 50 intakes.

The 22,5 MW Ilulissat hydropower project near the town of Ilulissat in Western Greenland harnesses the outflow of two glacial lakes by means of tunnels that tap into the bottom of the lakes (Figure 5).

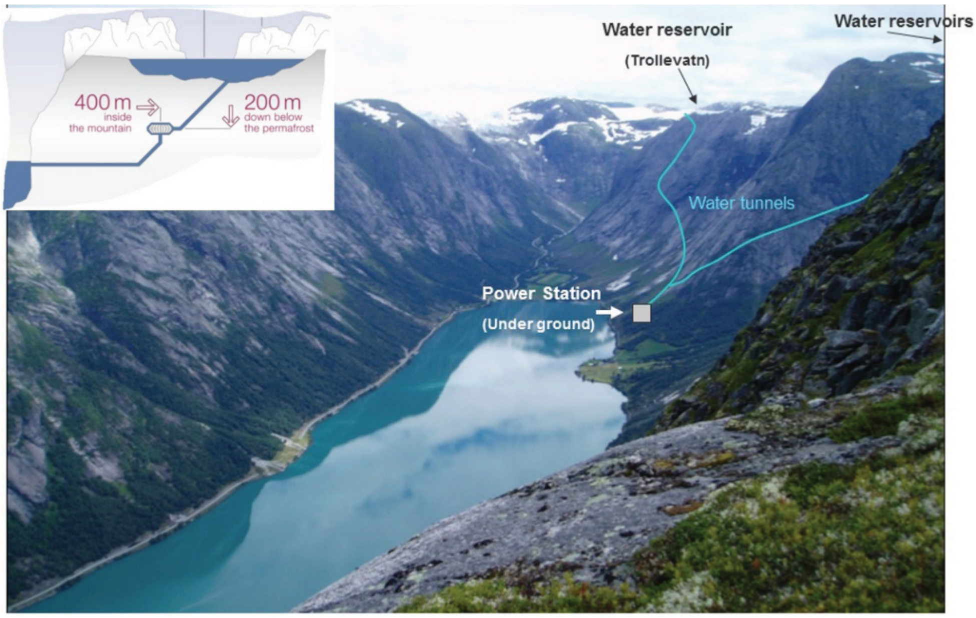

Figure 5 : The 22.5 MW Ilulissat Hydroelectric Project in Greenland

3.4 North America

In Canada, 10-20% of annual flow and 50% of summer flows in the Columbia River are derived from glacier melt water. Large facilities such as the 2805 MW Mica and 2480 MW Revelstoke hydroelectric plants are principally glacier fed (Fleming and Clarke, 2005). However, BC glaciers are receding. For example, over the period of 1985-1999 glacial recession was found to be occurring at a rate of about 22 km^3 per year, with many streams in glaciated basins in BC showing a statistically significant decrease summer stream flows (Stahl and Moore, 2006)indicating the need to manage the available resource and the expanding glacial lakes.

In Washington, there are about 700 glaciers that store as much water as all of remainder of the state's lakes, rivers, and reservoirs combined, Washington's North Cascade Glaciers release approximately 230 billion gallons of water during the summer that is nearly fully utilized for irrigation, salmon fisheries and power generation. However, all 47 monitored glaciers in the region are retreating (Pelto and Hedlund, 2001) with an expected loss of volume over a 25-year period in the range of 20-40%.

4. HYDROPOWER AND THE NATURAL HAZARDS OF NEPAL

Nepal has no known oil or gas reserves and only limited lignite deposits. All commercial fossil fuels (mainly oil and coal) are either imported from India or from international markets routed through India. In this context, waterand hydroelectric power represents a means for significant economic growth. Following the devastating impacts of the 2015 Gorkha Earthquake and aftershocks in Nepal, the country embarked on an ambitious reconstruction plan that includes plans to develop up 15 GW of new hydroelectric power plants over the next decade for use domestically and for export. While these ambitious plans are unlikely to be realized in their entirety due to logistical and funding issues, there is a need for the power in the region and there is significant activity.

A summary of the existing and planned hydroelectric power in the region is provided in Table 1. In Figure 6, the locations of existing and planned hydropower facilities in Nepal are shown.

Table 1:Existing and planned hydropower in Nepal.

Status	Number	Total Capacity (MW)	Average capacity (MW)	Total Demand (MW)
Operating	90	1,015	11.3	
Licensed for construction	30	1,855	61.8	
Issued survey license	307	17,617	57.4	
Totals	427	20,487	48.0	17,929

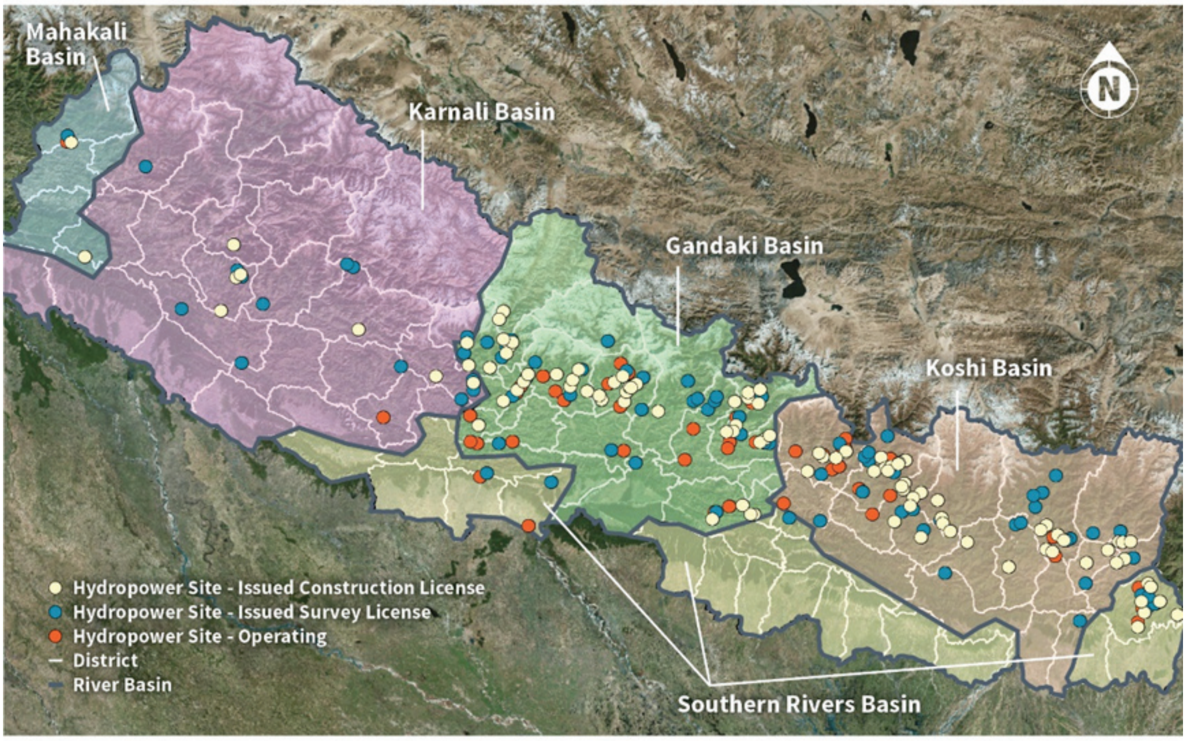

Figure 6 : Existing and Planned hydropower in the Seven Major Drainage Basins in Nepal

In geologically young and dynamically-active mountainous regions such as the Himalayas, the potential for natural hazards to occuris increased, introducing numerous challenges to hydroelectric power development (Reynolds, 2018, Donnelly, 2018). These hazards can be further compounded by the effects of climate change. For example, rising temperatures affect glaciers, snowfields and melt-water run-off. Thawing high-altitude permafrost can result in destabilization of steep mountain flanksgiving rise to catastrophic mass movements including Glacial Lake Outburst Floods (GLOF's) or Landslide Dam Outburst Floods (LDOF's). All of these natural hazards, as summarized in Table 2, need to be carefully considered when planning, constructing and operating hydroelectric facilities in mountainous regions.

Table 2 : Triggers of disasters, their types and possible causes (modified from Reynolds, 2015)

Event Trigger/Process	Type	Possible Causes
Earthquakes	Geophysical	Tectonic activity.
Cloudbursts or exceptionally prolonged heavy rainfall1.	Hydro-meteorological.	Atmospheric processes possibly coupled with effects of climate change.
Rock-/ice-avalanches and landslides.	Geomechanical	Debuttressing of mountain flanks from retreat of glaciers*. Retreat of glaciers*. Thawing of high-altitude permafrost*. Earthquakes. Heavy and prolonged rainfall. Pre-conditioning by earthquakes
Debris flows, mudslides including Landslide Dam Outburst Flood and Glacial Lake Outburst Floods.	Hydrological and geological	Heavy and prolonged rainfall. Thawing of permafrost and ice in moraine dams Saturation of material. Pre-conditioning by earthquakes

* Triggers and causes are not necessarily mutually exclusive and may be associated with changing climate

In addition to the impacts climate change has on natural hazards, it is also causing the worlds glaciers to melt, often at an accelerating rate. As glaciers recede, their retreat can lead to the formation of pro-glacial lakes dammed by moraines. These expanding lakes can in and of themselves increase the potential for natural hazards to develop. For example, if a rock and snow avalanche or a major landslide collapses into such a lake, an avalanche push wave can be generated that can overtop the moraine dam leading to its failure and a GLOF that can involve the discharge of millions of cubic meters of water and entrained debris that can flow for many tens of kilometers downstream.

Reservoir sedimentation is another significant factor in considering the future of hydropower development. The total volume of water stored in reservoirs used for hydropower and other purposes around the world currently exceeds 6,800 km^3 [White, 2001]. However, it has been estimated that 0.5-1% of global reservoir volume is lost every year due to sedimentation [White 2001, Morris, 2008]. It's estimated that, if these rates continue into the future, half of the world's reservoir storage would be lost within the next 50 to 100 years. As reported by Annandale, 2016, globally, storagespace to reservoir sedimentation global storage space percapita hasdecreased since about 1980 with a 2016 per capita net reservoirstorage space roughly equal to what it was in 1965 (Figure 7).Expanding glacial lakes provide a new source of water storage that can help to reduce this negative trend.

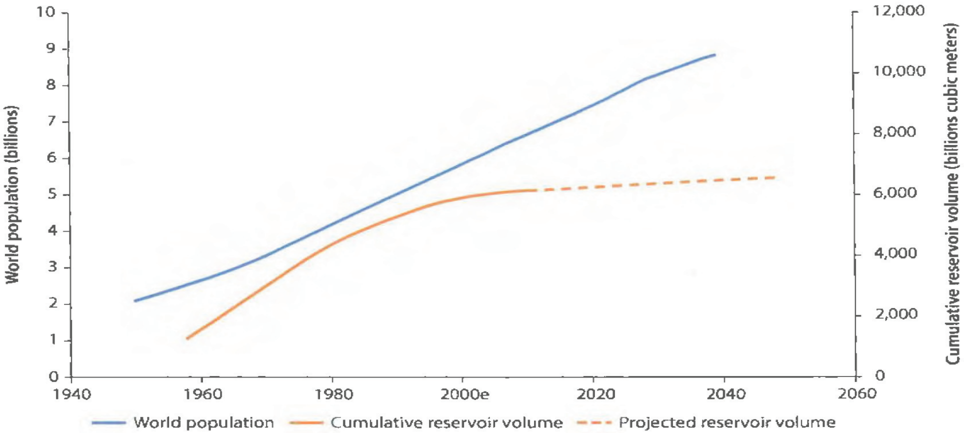

Figure 7 : Global Population Growth and Reservoir Storage Volume (Annandale, 2016)

5. GLACIAL LAKES IN NEPAL

Research based on topographic maps, aerial photographs and satellite images that began in 1999 identified 3,252 glaciers and 2,323 glacial lakes in Nepal (Figure 8). which can provide both positive and negative impacts to the countries existing and planned hydropower facilities. The researchers estimate 20 glacial lakes in Nepal are potentially dangerous, a figure that could increase as a result of glacial retreat. Almost all the glaciers in the Himalayas have been retreating since the Little Ice Age (1400-1650 AD). In more recent times, climate change is accelerating the retreat of mountain glaciers, enlarging existing glacial lakes and forming new ones. To-date, on average, the glaciers in Nepal have retreated about 1 km resulting in the formation of some substantial lakes.

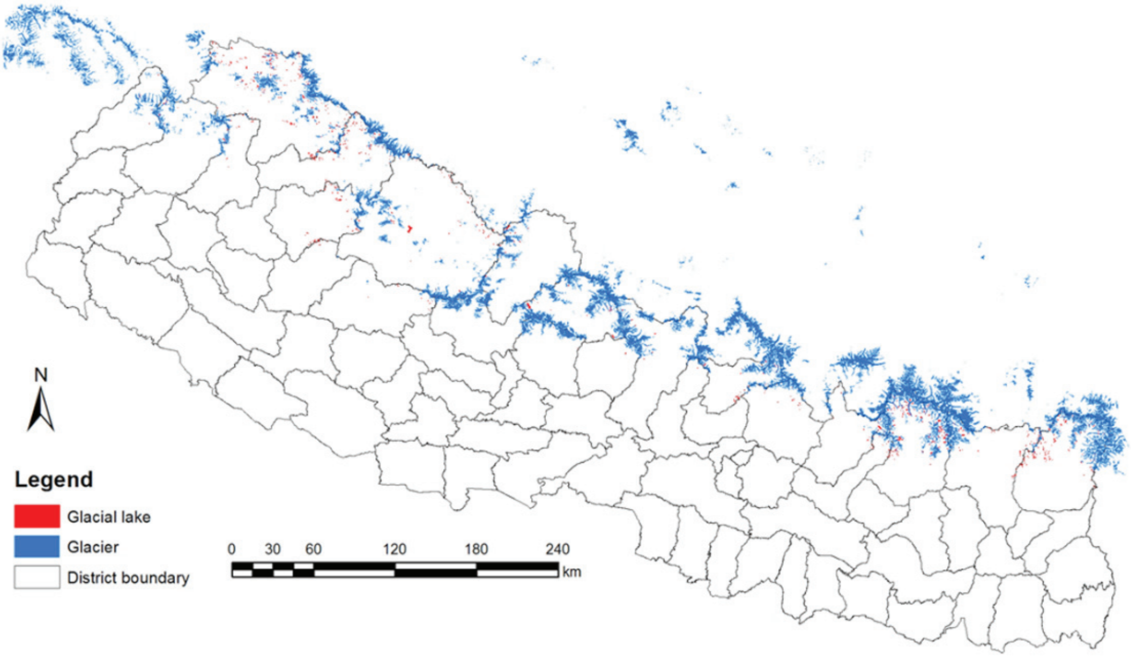

Figure 8 : The Glacial Lakes of Nepal

5.1 GLOF's in Nepal – Mitigating the Risks

Glacial lakes in Nepal are retained by moraines that are typically composed of over-consolidated (dense) cohesive materials. Such natural dams are generally quite stable, as evidenced by the large number of moraine-dammed glacial lakes and the relatively small number of GLOFs that have occurred historically. When GLOFs do occur, it is typically because of a triggering event, such as a landslide or rock/snow avalanche collapsing into a lake producing waves that can overtop and erode the moraine dam causing regressive erosion and the subsequent release of water in the form of a Glacial Lake Outburst Flood (GLOF) (Richardson and Reynolds, 2000). While GLOF's are relatively rare. major GLOF events can travel for more than 200 km downstream and can cause major devastation along the river channel such that GLOF's and other debris flow events still constitute a significant risk, if not the greatest risk, to hydropower development in mountainous regions (Donnelly, 2018).

As reported by Reynolds, 2018, all of the countries in the Himalayan region have recognized the hazards represented byGLOFs and, similar to other regions in the world are taking steps to manage the risk.In Nepal, the Tsho Rolpa Glacial Lake is located at an elevation of 4580m.The lake is approximately 3 km long, 0.5 km wide and up to 130 m deepcontaining approximately 80 million cubic meters of water. As such it is the largest glacial lake in Nepal. The Tradkarding glacier, which feeds the Tsho Rolpa glacial lake, is retreating at a rate of over 20 meters a year and, in some years within the last decade, reached 100 meters per year. The expanding lake is contained by a 140m high natural moraine dam that is considered to be only marginally stable. Failure of this natural dam would inundate parts or all of 20 villages for over 100 km downstream and threaten up to 6000 lives, the site for the 60 MW Khimti hydroelectric project, and other infrastructure.

The first phase of the risk reduction strategy for this glacial Lake includedlowering the water level in a hazardous lake through construction of an open channel controlled by sluice gates (Rana et al., 2000). The phase 1 remediation project was completed in 2000, with a reduction in lake level of 3.5 m achieved. The final scheme will involve lowering the lake by 20 m relative to its level in 1994 (Reynolds, 2015). However, funding of this final phase has been an ongoing point of discussion since 2002. Recently, the discussion has broadened into an assessment of the feasibility of both remediating this lake by lowering its water level and then using the storage capacity to provide dry season flow for additional power generation such as has been dome in other regions of the world.

A notional scheme (Figure 9) for the phase 2 remediation of Tsho Rolpa glacial lake being considered is to lower the lake by means of a power tunnel that wouldtap into the bottom of the lake transporting the lake water to a 4.3-km long tunnel that would utilize the water for power generation. The additional stream flow during the dry season would be transported travel downstream to the proposed Upper Tama Koshi Extension intake and into the headrace tunnel to the Upper Tama Koshi HPP site at Lamabagar. Currently, it is postulated that the construction costs could be recoveredwithin four years through the additional revenue from generation from the extra dry season flow thereby provid ing an ideal solution to a potentially serious problem.

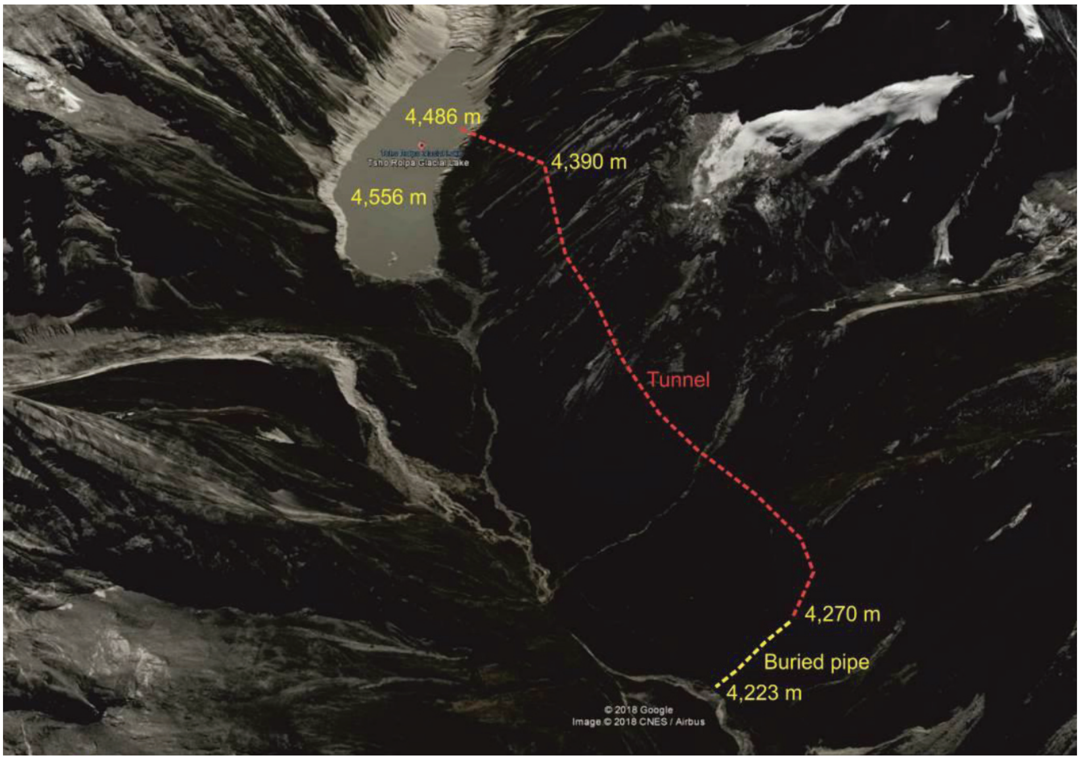

Figure 9 : Conceptual Tsho Rolpa Lake Remediation and Hydropower Scheme (Reynolds, 2018)

6. CONCLUSIONS

Climate change is causing widespread glacier retreat and a number of negative impacts such as diminishing water resources, shifts in runoff seasonality and an increase in the potential for natural hazards such as landslides, GLOF's and LFOF's to occur (Donnelly, 2018). However, glacial meltwater also represents a significant source of new stored energy world-wide (Farinotti, 2019) that can serve to counterbalance the world's loss in storage that is occurring due to sedimentation (Annondale, 2016), a process that can also be expected to accelerate in response to the impacts of climate change.

Farinotti, 2019 estimates that under a conservative climate change scenario, three quarters of the roughly 185,000 sites that are glacierized at present are anticipated to become ice-free by 2050. This will result in a loss of available meltwater for hydropower generation during the critical summer months. However, properly managed, Farinotti, 2019 determined that the potential additional storage volume in expanding glacial lakes would be enough to retain about half of the annual runoff potentially providing up to 300 to 700 terawatt-hours per year of practicably developable hydroelectric power, corresponding to about 13% of the current hydropower production worldwide. Aside from the obvious benefit of maintaining storage and redistributing available water resources, managing expanding glacial lakes can reduce the potential for a GLOF to occur by managing lake levels. Farinotti, 2016 undertook a first-order approach in order to assess whether 'replacing glaciers with dams is an option theoretically worth considering. While building dams at every glacier location is neitherrealistic nor sustainable, managing the available resources through dams and other means at a relatively small number of sites would provide significant benefits. For instance, it was determined that constructing dams at 1,000 of the roughly 185,000 glaciated sites examined would provide up to 31% of the total energy that is theoretically available. Environmentally, Nemergut, 2007 andHodson 2015 argue that managing glacial lakes also has environmental advantage because much of the infrastructure needed to exploit the lakes is underground and the new reservoirs are largely non-vegetated with relatively simple ecosystems where impacts can be readily managed.

Managing expanding glacial lakes as new storage reservoirs has been undertaken in countries around the world for almost eight decades, but not in Nepal where the need for hydroelectric power and the risks associated with GLOF's are significant. This solution has the potential to address both issues in a sustainable and environmentally friendly way.

REFERENCES

Andreassen, L.M., Elvehøy, H. Kjøllmoen, B. Engeset, and N. Haakensen. 2005. Glacier mass balance and length variation in Norway. Annals of Glaciology, 42: 317-325.

Annandale, George W., Gregory L. Morris, and Pravin Karki. 2016. Extending the Life of Reservoirs. *Sustainable Sediment Management for Dams and Run-of-River Hydropower.* The World Bank.

Braun, L. N., M. Weber, and M. Schulz. 2000. Consequences of climate change for runoff from Alpine regions. Annals of Glaciology, 31:19-25.

Donnelly, C. Richard, James H. Rutherford, Charly Cadou, William Moler, Samantha Taylor and Pravin Karki. 2018. Lessons Learned from Five Hydroelectric Power Projects in Nepal in the Aftermath of the 2015 Gorkha Earthquake. 26th ICOLD Congress and 86th Annual Meeting, ICOLD - Question 101, Vienna.

Ehrbar,Lukas. David F. Schmocker, F. Vetsch and Robert M. Boes. 2018. Hydropower Potential in the Periglacial Environment of Switzerland under Climate Change. Swiss Competence Center for Energy Research.

Farinotti, D., Alberto Pistocch and Matthias Huss. 2016.From dwindling ice to headwater lakes: could dams replace glaciers in the European Alps?Environ. Res. Lett. 11 (2016) 054022 doi:10.1088/1748-9326/11/5/054022.

Farinotti, D., Round, V., Huss, M., Compagno, L. and H. Zekollari. 2019. Large hydropower and water-storagepotential in future glacier-free basins. *Nature* 575: 341-356.

Fleming, S. and G.K.C. Clark. 2005. Attenuation of high-frequency interannual streamflow variability by watershed glacial cover. ASCE Journal of Hydraulic Engineering, 131: 615-618

Fountain, A.G and W.V. Tangborn. 1985. The Effect of Glaciers on Streamflow Variations. Water Resources Research, 21: 579-586.

Hodson, A. Ben Brock, David Pearce, Johanna Laybourn-Parry and Martyn Tranter. 2015. Cryospheric ecosystems: a synthesis of snowpack and glacial research Environ. Res. Lett. 10 110201 doi:10.1088/1748-9326/10/11/110201.

Morris, G.L., G. Annandale, and R. Hotchkiss. 2008. Reservoir Sedimentation in Sedimentation Engineering, ASCE.

Nemergut, D. R., S.P. Anderson, C.C. Cleveland, A.P. Martin, A.E. Miller, A. Seimon and S.K. Schmidt. 2007. Microbial community succession in an unvegetated, recently-deglaciated soil. Microb. Ecol. 53, 110-122. (doi: 10.1007/s00248-006-9144-7)

Normatov, I., and G. Petrov. 2006. Reservoirs and their role in social and economical development in Tajikistan and Central Asia. In Dams and Reservoirs, Societies and Environment in the 21stCentury. Taylor Francis Books, London, UK.

Paul, F., A. Kääb, and W. Haeberli. 2007. Recent glacier changes in the Alps observed by satellite: Consequences for future monitoring strategies. Global and Planetary Change, 56, 102-111.

Pelto, M.S. and C. Hedlund. 2001. The terminus behavior and response time of North Cascade glaciers. Journal of Glaciology, 47: 497-506

Pelto, M.S. 2008. Impact of Climate Change on North Cascade Alpine Glaciers, and Alpine Runoff. Northwest Science, 82: 65-75.

Richardson, S.D. and J.M. Reynolds. 2000. An overview of glacial hazards in the Himalayas. Quaternary International, 65/66(1):31-47.

Reynolds, John M., C. Richard Donnelly, Jim Rutherford, Samantha Taylor, Pravin Karki and Rajeswar Man Sulpya. 2018. Accounting for Natural Disasters in Dam Design and Dam Safety. CDA 2018 Annual Conference Québec, QC, Canada

Reynolds, John M. The role of Disaster Risk Management strategies in managing natural hazards. 2018. Keynote presentation at ASIA 2018, Da Nang, Vietnam.

Reynolds, John M. 1992. The identification and mitigation of glacier-related hazards: examples from the Cordillera Blanca, Peru. In: McCall, G.J.H., Laming, D.C.J. and Scott, S. (eds), Geohazards, London, Chapman & Hall, pp. 143-157.

Singh, P., U. Haritashya, N. Kumar, and Y. Singh. 2006. Hydrological characteristics of the Gangotri Glacier, central Himalayas, India.Journal of Hydrology, 327: 55-67.

Stahl, K. and R. Moore. 2006. Influence of watershed glacier coverage on summer streamflow in British Columbia, Canada. Water Resources Research 42: W06201, doi:10.1029/2006WR005022.

Stenborg, T. (1970). Delay of runoff from a glacier basin. Geografiska Annaler 52A, 1-30.

Vergara, W., A. Deeb, A. Valencia, R, Bradley, B. Francou, A. Zarzar, A. Grunwaldt and S. Haeussling. 2008. Economic Impact of rapid glacier retreat in the Andes. EOS, 88(25): 261-262.

White, R. 2001, Evacuation of sediments from reservoirs, Thomas Telford Publishing, London, UK.

Zhang, Y., Liu S., Xu, J., and D. Shangguan. 2008. Glacier change and glacier runoff variation in the Tuotuo River basin, the source region of Yangtze River in western China. Environmental Geology, 56: 59-68.