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An integrated assessment approach for estimating the economic impacts of climate change on River systems: An application to hydropower and fisheries in a Himalayan River, Trishuli

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ABSTRACT

Changes in snow and glacier melt and precipitation patterns are expected to alter the water flow of rivers at various spatial and temporal scales. Hydropower generation and fisheries are likely to be impacted annually and over the century by seasonal, as well as long-term changes, in hydrological conditions. In order to quantify the effect of climate changes on hydropower and fisheries, we developed an integrated assessment framework that links biophysical models (positive degree-day model, hydrologic model, run-of-river power system model, and fishery suitability index) and economic models. This framework was used to demonstrate the framework's utility for gaining insights into the impacts of changed river flow on hydropower and fisheries of the Trishuli River in the High Mountain Asia (HMA) Region (from the Hindu Kush and Tien Shan mountain ranges in the west to the Eastern Himalaya). Remotely sensed and in situ data were used to quantify changes in snow and glacier melt in Langtang glacier and resultant change in hydrologic flow in the Trishuli River upstream of the Trishuli hydropower plant. Future discharges were projected using climate data derived from the Cubic Conformal Atmospheric model with 50-km resolution in Representative Concentration Pathway (RCP) 8.5 and RCP 4.5 climate scenarios. Results suggest that, in the future, the Trishuli River will experience modest increases in the economic value of the hydropower resource and fisheries as a result of higher snow and glacial melt. Increased flow in the months of March and April attributed to increased glacier melt translated to an increase in electricity generation. However increased flow in June and July when the snow and glacial melt peak is coupled with monsoon precipitation could not be fully utilized due to hydropower plant capacity constraints. Fishery suitability in the Trishuli River would be greater than 70% of optimal under both RCP 4.5 and RCP 8.5. Power economic results do not vary significantly for the next thirty years because flow increases under RCP 8.5 and resultant energy production are more pronounced in the later part of the century. The framework utilized in this study can be expanded in the future to analyze hydropower infrastructure as well as fisheries conservation in the upstream HMA basins from Afghanistan through Bhutan.

1. Background and introduction

Climate-mediated changes in the melting of snow and glaciers and in precipitation patterns are expected to alter the flow of the rivers at various spatial and temporal scales (Field et al., 2014; Immerzeel et al., 2009; Akhtar et al., 2008; Hock et al., 2005), which in turn could impact socioeconomics of the regions (Barnett et al., 2006; Viviroli et al., 2007, Moors et al., 2011). Himalayan Rivers provide the basis for food and energy production for more than a billion people and support diverse ecosystems in downstream areas of the High Mountain Asia (HMA) region that stretches from the Hindu Kush and Tien Shan mountain ranges in the west to the Eastern Himalaya. Because the economic value of a river depends on economic activities governed by river flow, changes in seasonal and long-term hydrological conditions due to climate change may have far-reaching economic consequences annually and over the century.

While energy production is the priority in the HMA region, agriculture is the backbone of the economy and nature-based tourism is a

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major source of the Gross Domestic Product (GDP). Countries of the region have plans to develop hydropower resources to meet rising electricity demands for the growing and developing population. Rivers are also the basis for irrigated agriculture and the livelihood of rural populations. The Ganga-Yamuna and Brahmaputra Rivers are used to irrigate 0.5 million km^2 (60% of irrigated land) and 6000 km^2, respectively, in India (GOI, 2010). Fish biodiversity supported by the rivers is the main source of income for 0.5 million fishermen in India and 30,000 in Nepal (FAO, 2012).

Critical climate change impacts have been demonstrated in the HMA region. According to an Intergovernmental Panel on Climate Change (IPCC) report (Field et al., 2014), an increase of 2.4 °C was observed in the mid-latitude semiarid region of Asia during the cold season (November to March) from 1901 through 2009. From 1967 to 2012, snow cover in the northern hemisphere decreased by an average of 1.6% (0.8% to 2.4%) per decade in March and April and by an average of 11.7% (8.8% to 14.6%) per decade in June (Field et al., 2014). Climate modeling conducted using Representative Concentration Pathway (RCP) 2.6 predicts that temperatures in the mid- and late-21st century would increase by 2 °C to 3 °C above the late-20th-century baseline over the high latitudes in South Asia (Field et al., 2014). Such increases in temperature would result in an accelerated thaw of glacial ice packs. The report projected that spring snow cover in the hemisphere will decrease by 25% under RCP 8.5 by the end of the 21st century.

The contribution of snow and glaciers to river flow for high-altitude areas is important for hydropower production in Nepal. Recent studies by Racoviteanu et al. (2013); Brown et al. (2014), and Gupta et al. (2015) show that glaciers contribute more than 50% of the total annual streamflow in the Langtang River Basin. However, the glaciated area in Nepal decreased by 24% from 1977 to 2010 (Bajracharya et al., 2014). Given the heterogeneity in topography and distribution of glaciated areas within river basins, pressing questions include (1) to what extent does projected climate change affect snow and glacier melt; (2) to what extent does melting dynamics change the runoff regimes in these rivers; and (3) what economic sectors are significantly affected by climate change? While the contribution of snow and glaciers to river runoff has been studied in a few selected HMA river basins (e.g., Brown et al., 2014; Alford and Armstrong, 2010; Bookhagen and Burbank, 2010), the spatiotemporal impacts of climate-mediated changes on streamflow are not well understood for the rivers in the region. Furthermore, it is important to understand the magnitude and extent of such changes on economic values for specific downstream resources and the effects on regional economics. The estimated economic value of such impacts on river flow is crucial information required by the Nepal government for effective water resource planning and management.

While changes in flow would have a range of potential impacts on downstream ecosystem services, our focus is on the effects of changes in the timing and magnitude of flows on the economics of hydropower generation and downstream fisheries. Currently Nepal generates 92% of its electricity from hydropower (Asian Development Bank, 2012) and the peak annual electricity demand is almost 1000 MW. To meet the expected rapid increase in future demand and trade with India, the Department of Electricity Development granted licenses for development of new hydropower plants that if constructed would provide 5465 MW of additional generating capacity (NEA, 2015).

The ability of decision makers to understand the economic risks of climate change on existing and planned hydropower is hampered by the uncertainty of climate-based changes in river flow and the lack of understanding of the linkages between river flow regimes and the economic benefits generated by river systems through energy production and ecosystem services. This places investments in infrastructure development for hydropower, fisheries, and irrigation at high risk. A greater understanding of the impacts of climate change on river flow, especially how that translates to economic return from existing and proposed hydropower plants and how downstream river functionality would be affected under altered water availability scenarios, is critical to the sustainable management of river basins within the region.

This paper was developed as part of a larger study funded by the National Aeronautics and Space Agency (NASA) for understanding these potential effects in the HMA region. Here we describe an integrated assessment framework for evaluating the impacts of climate-mediated changes in river flow on downstream ecosystem services and demonstrate the application of the framework to a portion of the Trishuli River basin in Nepal. While the framework was developed for analysis of hydropower plants, agriculture, and fisheries, the example presented in this paper focuses only on a hydropower plant in Trishuli River and fisheries upstream and downstream of the plant.

2. Methods

2.1. Framework for assessments

An overarching question the HMA region is facing is how climate change will impact the economies of these developing nations, which are based on climate-sensitive energy production, agriculture, and nature/biodiversity-based tourism. The total economic returns from hydropower production, food (irrigated land) production, and fisheries are expected to change in the future as a result of climate-mediated changes in river runoff. The water-energy-food nexus will be a fundamental and increasing challenge (Russi et al., 2013) as the unique ecosystem is expected to be greatly impacted in the region. Water resource managers in the region will need to address trade-offs regarding the development of additional hydropower plants to meet energy needs and maintain downstream ecosystem services in order to maximize net long-term gains.

Our assessment framework integrates an economic valuation model with biophysical models of climate, remote sensing, snow and glacier hydrology, energy production, and environmental performance (Fig. 1). The framework is based on the integrated assessment approach (Forney et al., 2013; Antle et al., 2001) to estimate changes in total economic values corresponding to changes in physical conditions. Economic value is estimated as the value of ecosystem services from the river. Ecosystem services are attributed to provisioning, regulating, cultural, and support services such as hydropower generation, irrigation, drinking water, flood control, water supply to wildlife, rafting, fishing, and waste assimilation services. While the framework can be applied to estimation of all ecosystem services, our focus is only on the values of hydroelectricity and fisheries. Controlling future floods may become increasingly important under a warmer climate scenario. In our study we focused on current run-of-river hydropower plants that cannot be used

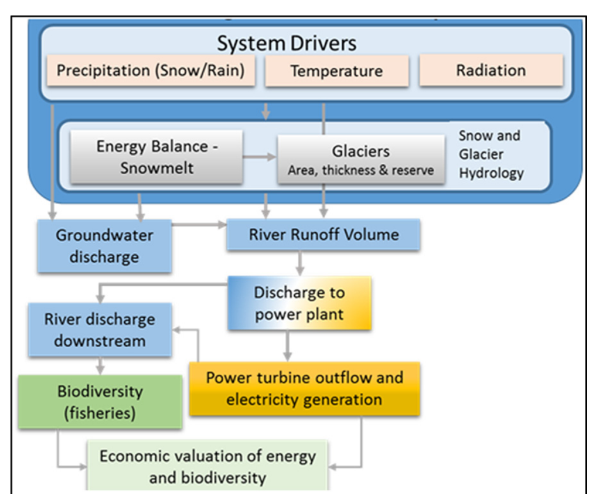

Fig. 1. Integrated assessment framework schematics.