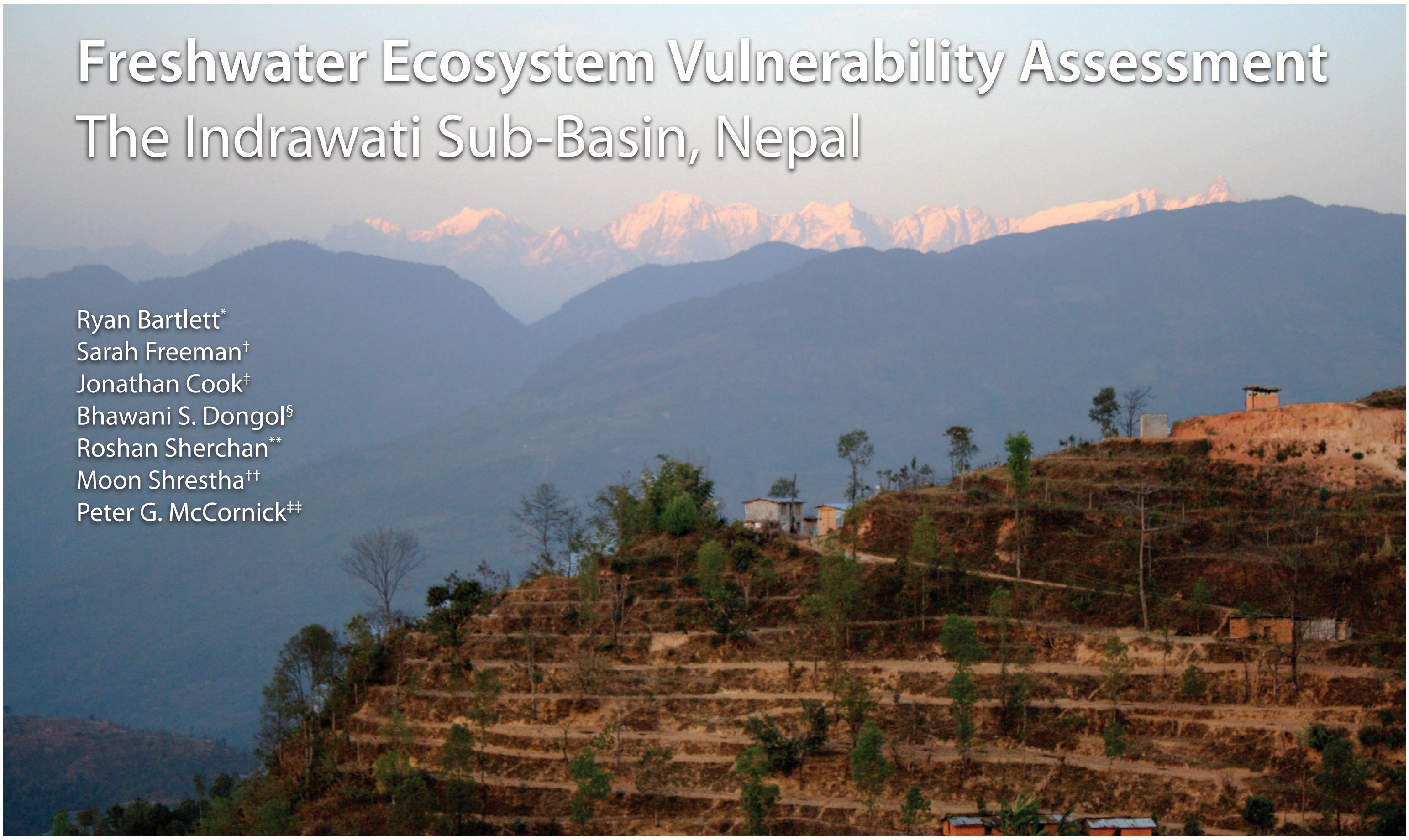
WORKSHOP REPORT



Freshwater Ecosystem Vulnerability Assessment
The Indrawati Sub-Basin, Nepal

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Cover photo by Ryan Bartlett

CONTENTS

INTRODUCTION

This report is part of a project of WWF Nepal and the Nepalese Water and Energy Commission Secretariat (WECS). It outlines the discussions and conclusions of three workshops held in Nepal to determine the vulnerability of the Indrawati sub-basin to the impacts of climate change and development within the context of climate change vulnerability at the national level. Held over the course of four days in Kathmandu and in the Sindhupalchok district headquarters of Chautara, the workshops brought together a diverse group of more than 60 participants, including Nepali national experts, local bureaucrats, and most importantly, local water users and subsistence farmers with direct knowledge of resource management issues in the basin.

Using a modified version of the ecosystem-based and water resource-focused vulnerability assessment methodology (Flowing Forward) developed by the World Wildlife Fund (Le Quesne et al. 2010; Matthews and Wickel 2010), workshop participants evaluated the combined impacts of climate change and development in the basin on both vulnerable ecosystems and local livelihoods. With this understanding, they outlined potential remedies, from macro-level policy reforms to on-farm technical capacity building.

We then connect the outcomes of this process with some additional analysis of two key economic sectors (hydropower and agriculture) that are important in the Indrawati basin. We briefly assess the vulnerability of these sectors to climate change and identify some potential adaptation options. Because the Indrawati is so relevant to larger national-level resource management questions, especially those related to large-scale water infrastructure, we also summarize some of the issues related to these two sectors at the national level.

The workshops were convened by WWF Nepal and WECS with assistance from the Nicholas Institute for Environmental Policy Solutions at Duke University and the World Wildlife Fund-United States (WWF-US). The main goals were to

- determine the vulnerability of key ecosystems and the factors that contribute to it;
- analyze future water use under development and climate change scenarios;
- determine impacts and risks from development and climate change to ecosystems, livelihoods, and infrastructure;
- analyze natural, institutional, and infrastructural adaptive capacity; and
- develop options and strategies for adaptation.

Information gathered at the workshops will be used to advance WWF's larger goal: developing a vulnerability assessment methodology that can be applied to all Himalayan river basins and sub-basins. In particular, this case study will aid the WWF Nepal/WECS Indrawati sub-basin project, the main goal of which is to "reduce significantly the vulnerability of people, biodiversity and economic investments in the face of climate change and other local anthropogenic activities" (WWF Nepal 2010).

This report is thus an effort to provide a vulnerability assessment case study that will not only help elucidate the likely future changes to water resources in the basin and throughout Nepal, but also aid local governing bodies and other NGOs by expanding on a relatively sparse knowledge base. Most importantly, however, this report will help resource managers and decision makers in the Indrawati determine the most appropriate and effective adaptation interventions that will both support development and strengthen the resiliency of local populations and ecosystems to the impacts of climate change and economic development.

The Flowing Forward methodology (Le Quesne et al. 2010; Matthews and Wickel 2010) is a freshwater ecosystem-based tool that assesses the impacts of climate change and development on both ecosystems and the local livelihoods directly dependent on them. It has been used to analyze water futures in the Okavango Delta, the Breede River basin in South Africa, the Tocantins-Araguia sub-basin of the Amazon in South America, the upper Mekong basin in China, and the Siphondone-Stung Treng area of the Mekong River basin (Le Quesne et al. 2010; Kistin and McCornick 2009; Farrington et al. 2010). This case study seeks to further refine and apply this methodology in the Indrawati sub-basin in Nepal, but also to incorporate, for the first time, direct inputs from local water users through workshops at the community level.

Unlike other vulnerability assessment tools, which are largely focused on populations and socioeconomics, Flowing Forward explicitly addresses ecosystems and the critical services they provide for both humans and biodiversity at the basin and sub-basin scales—especially those services that relate to water resources. Numerous authors working on vulnerability assessment have identified the importance of assessing water resources, as they are the primary vehicles through which most impacts of climate change will occur (Matthews and Wickel 2009; Matthews and Le Quesne 2009). For Nepal, a country with vast water wealth and a high percentage of the population directly dependent on water resource ecosystem services for generating subsistence-based local livelihoods, analyzing these linkages is especially critical.

The Flowing Forward methodology's objectives include establishing goals and criteria that are geographic and temporal in scope. The methodology's risk assessment is a three-step process involving a top-down assessment of development and climate scenarios, a bottom-up assessment of ecosystem vulnerability, and a synthesis of the two. Lastly, the methodology provides an assessment of adaptive capacity and adaptation options.

This report describes the Indrawati and the scope of the analysis. It then outlines the various risks in the basin and adaptive capacity and adaptation options, as assessed by workshop participants. It concludes with recommendations for resource managers in the sub-basin.

THE INDRAWATI RIVER BASIN

Physical Conditions and Ecological State

Located in central Nepal and part of the larger Koshi basin, the Indrawati River originates in the high Nepali Himalayas, eventually joining the Sun Koshi River that flows into the Koshi that then connects with Ganges River in northern India. With a total length of approximately 59 kilometers and a catchment area of 124,000 hectares, the Indrawati basin (see Figure 1) has 7 major tributaries that contribute to its flows: the Larke Khola, Yangri Khola, Melamchi Khola, Jhyangri Khola, Chaa Khola, Handi Khola, and Mahadev Khola (Bhattarai et al. 2002).

Climate in the basin is primarily governed by the interaction of the South Asian monsoon system and the Himalayas. Heavy rainfall, relatively high temperatures, and humidity characterize the summer months from roughly mid-May to mid-October; nearly half the total annual rainfall occurs in the months of July and August. The rest of the year is considerably dryer, with roughly 7% of the annual total rainfall occurring from November to April. Average annual rainfall has a wide range of 1,100 to 3,800 millimeters; the highest totals are reported at the higher altitude-measuring stations. Temperatures range from 5 degrees to 32.5 degrees Centigrade (Bhattarai et al. 2002; Sharma 2002). The basin's many microclimates have distinct weather and temperature patterns. As Figure 2 shows, major differences in climate are observed at the different altitudes of the basin's three main ecoregions:

- **High Himalayas.** At an altitude higher than 5,000 meters, this ecoregion is characterized by cold temperatures, high peaks, glaciers, rocky slopes, and rough terrain with incised valleys and steep slopes, and precipitation mostly falling as snow.
- **High Mountains.** At between 5,000 and 3,000 meters, the High Mountains are characterized by a cooler, temperate climate, still steep terrain, and high precipitation levels.
- **Middle Mountains.** At lower than 3,000 meters, this ecoregion has the most productive farming valleys, the warmest temperatures, and the highest rainfall totals (Kansakar et al. 2004; Shrestha 2010).

Within these regions, climate can vary significantly. Mountain ridges have, for example, been shown to receive four to five times as much rainfall as nearby valleys (NCVST 2009).

The Indrawati's notable biodiversity, conserved in part by Langtang National Park, cuts across the entire higher-altitude alpine region of the basin. Established in 1976, the 1,710-square-kilometer park contains more than 1,000 vascular

Figure 1. Map of the Indrawati river basin.

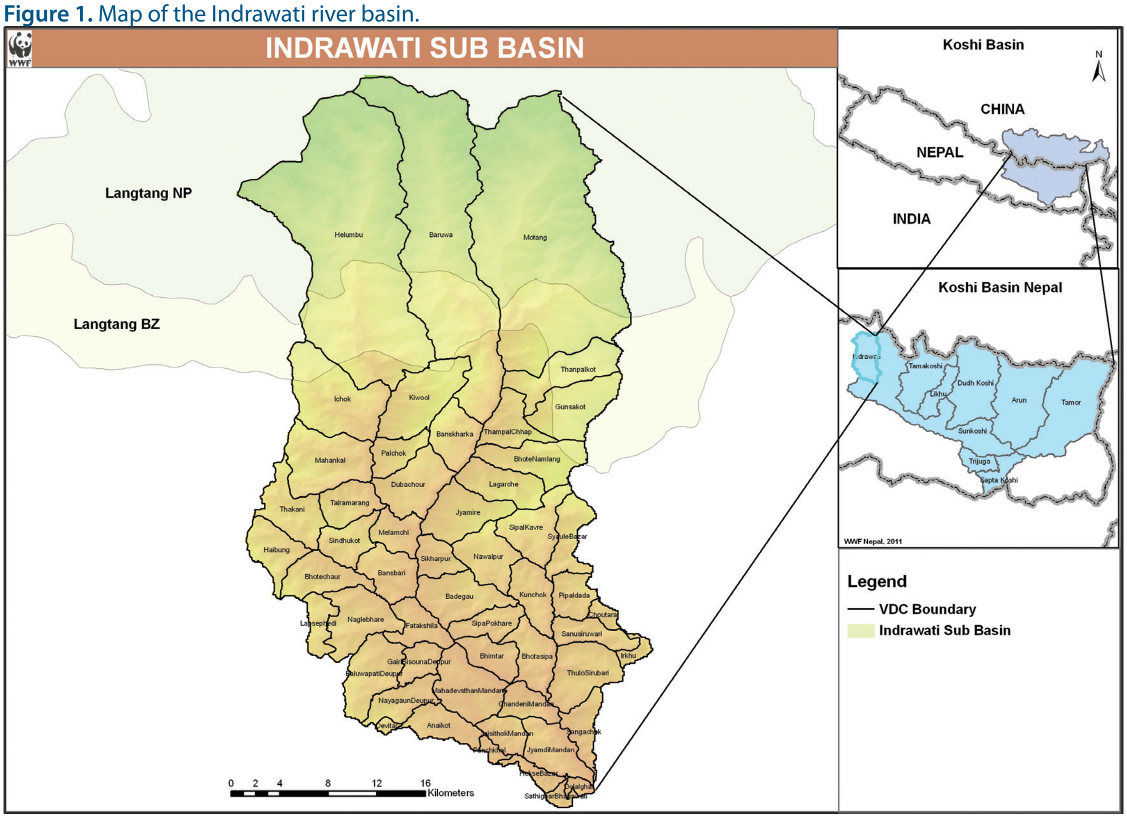
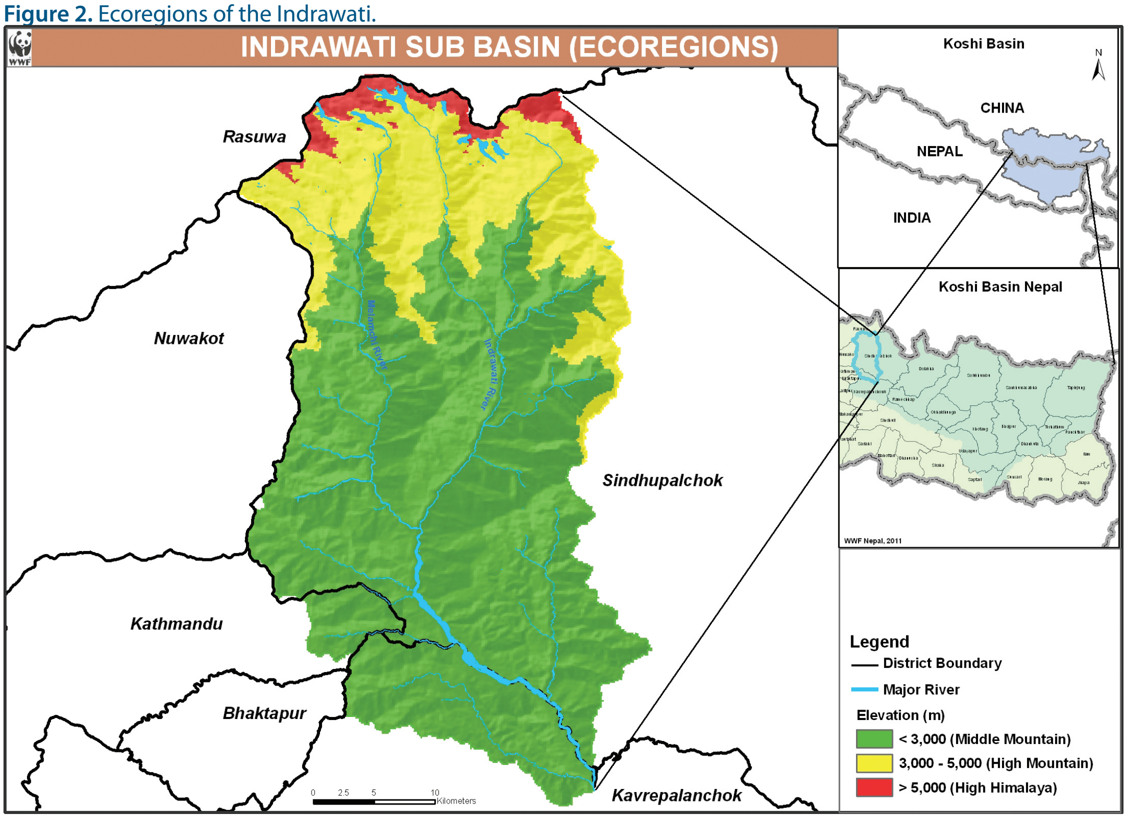


Figure 2. Ecoregions of the Indrawati.



plant, 45 mammal, 30 fish, and 345 bird species, including the Snow leopard, Red panda, Musk deer, Tibetan wolf, Blue sheep, Clouded leopard, and several globally threatened[1] bird species (Bhuju et al. 2007).

Langtang is also home to the Panch Pokhari (Nepali for "five lakes") wetlands, a significant water source for the Indrawati that is particularly vulnerable to development pressures ranging from overgrazing and deforestation to water pollution. The wetlands provide valuable ecosystem services to the basin, including groundwater recharge, flood control, sediment trapping, and water for wildlife and livestock in the catchment. The site is also home to endangered species like the Red panda and Snow leopard and to many migratory and non-migratory bird species (Bhuju et al. 2007).

Key Ecosystems

Within the basin's three main ecoregions, workshop participants—scientists and policy makers at the national level and water users and farmers at the local—identified eight key ecosystems as significant from the perspectives of local economic livelihoods and larger ecosystem functionality. Following the Flowing Forward methodology, they serve as the main organizational units in the basin for analyzing vulnerability.

High Himalayas

- **Cryosphere and Rugged Mountains (glaciers, snow, and permafrost).** The dominant ecosystems in the High Himalayan ecoregion, these mountains are the source waters for the Indrawati and its tributaries ("water towers") and are of cultural and religious importance. These systems are also important for their biodiversity and tourism, as they lie entirely within the bounds of Langtang National Park.

High Mountains

- **Alpine Forest (conifer and shrublands).** Dominating land use in the High Mountain ecoregion, this ecosystem provides numerous ecosystem services, including erosion control and slope and soil stabilization, water regulation, climate regulation, microclimate control, biodiversity habitat, non-timber forest products (NTFPs) relied on by local populations for livestock, and detritus for fertilizer. It also more directly supports local livelihoods by providing biomass fuel for cooking and timber for building materials.
- **Rangelands (pasture and open grazing lands).** Existing throughout the higher altitudes of the High Mountains, this ecosystem provides habitat for the nomadic trans-human herder populations and their livestock as well as notable biodiversity, including Snow leopard, Musk deer, and important medicinal and aromatic plants (MAPs).
- **Wetlands (including lakes and ponds).** The high-altitude wetlands of the High Mountains, mainly the Panch Pokhari area, provide source waters for the Indrawati River, migratory bird habitat, groundwater recharge, flood control, sediment trapping, drinking water for livestock, and water quality regulation for downstream flows. The wetlands are also culturally and religiously important as the site of the annual Janaipurnima festival to which approximately 10,000 Hindus make a pilgrimage (Bhuju et al. 2007).

Middle Mountains

- **Mixed Forest (hardwood and broadleaf).** The most expansive and valuable forest ecosystem in the basin, mixed forests are primarily found in the Middle Mountains (1,200–3,000 meters) and are critical for both local livelihoods and biodiversity. They are habitat for notable species, including the Red panda and Rhododendron, but provide even more critical ecosystem services, including groundwater recharge, NTFPs, MAPs, timber, fuelwood, fodder for livestock and fertilizer, and perhaps most importantly, slope stabilization through erosion and flood control and landslide mitigation.

Trans-regional (Basin-wide)

- **Rivers and Streams.** Freshwater ecosystems play an important role throughout the basin, providing aquatic habitat for subsistence-based community fisheries and other significant biodiversity. Other ecosystem services include irrigation for commercial agriculture in the lowland areas, water for grain mills, national grid-connected hydropower,

1. Identified by Birdlife International using IUCN Red List and other information. See http://www.birdlife.org/action/science/species/global_species_programme/red_list.html for more information.

drinking water for populations throughout the basin and Kathmandu (located in the adjacent sub-basin) through the under-construction Melamchi inter-basin transfer, and sediment for the large sand and gravel mining industry along the banks of the Indrawati river. Sand and gravel mining is particularly lucrative in the Indrawati, as it supplies construction materials for the rapidly growing neighboring Kathmandu valley. Due to poor regulation, it has a number of negative effects on in-stream and downstream ecosystems.

- **Agroecosystems.** Though man-made, agroecosystems nonetheless play a vital role in the hydrology and ecology of the basin, from the subsistence-based agriculture of the High Mountains to the commercial production of the Middle Mountains. They support a variety of crops critical to local livelihoods and food security within the basin and increasingly to urban populations in Kathmandu that have transitioned away from agricultural production.

Land Use and Other Socioeconomic Conditions

Population characteristics in the basin reflect topography; the more isolated rural portions are found in the higher reaches of the High Mountains, and denser rural and semi-urban areas are found in the lower elevation areas of the Middle Mountains. An estimated 185,000 people live in the roughly 1,240 square kilometer area of the basin, creating a population density of approximately 150 people per square kilometer (Karki 2005), which is lower than that of the rest of Nepal, but higher than that of many developed and developing nations (World Bank 2010). The basin lacks any single distinct large urban area, in large part due to its proximity to Kathmandu, but has many smaller rural village centers, including the Sindhupalanchok District headquarters of Chautara. Even with significant rural-urban out-migration, population growth in the basin remains positive at an annual rate of 1.6%. If this growth rate is maintained, the population in the Indrawati would increase by roughly 38% over the 2005 level by 2025 (Karki 2005).

Land use in the basin is generally characterized by small-scale, subsistence-based agriculture and commercial agriculture for urban markets (primarily in the lowest altitudes of the Middle Mountains) as well as natural forest cover. With average farm-size holdings of less than 1 hectare (and more than 60% less than 0.5 hectares on at least two of the tributaries), tenant farming, whereby small plots of land are rented from a larger landowner, is commonplace. More than 90% of the cultivable land in the Palchowk Beltar and Bhattar irrigation systems, and 70–80% in the Taruki Besi systems, for example, are under tenant farming (Bhattarai et al. 2002). In most cases, farming is rain fed, and the vast majority of irrigable land is already under irrigation (see Table 1 below). Traditional practices, such as the use of animal fertilizer, are widespread; however, according to workshop participants, chemical fertilizer use is expanding in some areas. Rice is the most prevalent crop, along with wheat, maize, and millet; higher cropping intensities and longer growing seasons allow for up to four crop cycles in irrigated areas at lower altitudes. However, some workshop participants noted a gradual shift away from rice and toward wheat and millet due to changes in the monsoon, and potatoes and tomatoes are of growing interest for commercial production for urban markets. Forest territory in the basin remains considerable, comprising the largest percentage of the catchment area (Karki 2005).

Table 1. Land use in the Indrawati sub-basin.

Land Use	Area (km^2)	Area (%)
Forest Land	543.3	43.8
Agricultural Land	407.3	32.8
Ice and Snow Covered	148.1	11.9
Irrigable Area	70.7	5.7
Irrigated Land	50.8	4.1

Source: Karki 2005.

Households in the Indrawati are heavily reliant on natural resources; more than 60% of the population depends on agriculture for its livelihood, and forest products and livestock provide critical additional support. Poverty statistics mirror this dependence: a large portion of the basin's inhabitants is under the national poverty line, which is more than double the 2004 national average (World Bank 2010). Like other aspects of the basin, land use trends differ markedly across the three ecoregions:

- **High Himalayas.** Economic activities are limited to livestock rearing and milk production due to geophysical and climate conditions, including minimal viable agricultural lands, low soil fertility, and a short growing season. Extremely limited access to national infrastructure further inhibits more diverse land uses, making the region home to some of the poorest populations in the basin. Langtang National Park and its surrounding buffer zone further inhibit major land uses, but they do support small populations with areas for grazing and fuelwood collection. Farming, where possible, is limited to rain-fed monocultures that are vulnerable to failure, which can be devastating given a cold climate that allows for only one annual harvest (Bhattarai et al. 2002).

- **High Mountains.** With lower, somewhat more hospitable altitudes, populations here face fewer land use constraints than those in the High Himalayas of the catchment, but they still tend to be isolated from markets and infrastructure and to be limited to steep-slope, rain-fed agriculture. The small window for the growing season is dependent on the timing of the summer monsoon and some cascade irrigation systems (Shrestha 2004). The primary crops grown in this region are rice, maize, millet, potatoes, and other vegetables; some fruit trees have been recently introduced. Tourism also affects land use in these higher altitudes; for example, during the Hindu Janai Purnima festival, visiting pilgrims contribute to overgrazing, water pollution, and over-exploitation of fuelwood, timber, and other NTFPs (Bhuju et al. 2007).
- **Middle Mountains.** Relative to the higher altitudes, this region's infrastructure—including irrigation and some roads—is better developed, the soil is more productive, and the growing season is longer (three to four cycles for some crops), allowing greater crop diversification, including commercial agricultural production of high-value vegetables and fruit. Access to markets, both locally and in Kathmandu, is also easier, leading to more income from agricultural sources and more opportunities in other non-agricultural sectors. The largest non-agricultural land user in the Indrawati, the sand and gravel mining industry, is also located in the lower reaches of the basin along the riverbeds of the main stem of the Indrawati. Land uses are thus generally much more diverse in the Middle Mountains than at the basin's higher altitudes.

Water Resources

Water in the Indrawati is used for irrigation, drinking water, livestock, hydropower, water mills, and natural ecosystems; agriculture is the main consumptive use. With nearly 90% of total average annual inflows in the basin discharging from the basin, the Indrawati can be considered a surplus basin, that is, its available water exceeds current consumptive demand. However, in recent decades, demand has also increased significantly, resulting in more frequent incidences of localized scarcity, especially in the dry season. The 90% figure, which reflects a water accounting based on data from 1970 to 1990, is thus likely much lower today (Bhattarai et al. 2002; Shrestha 2004). Furthermore, such general statistics belie basin hydrology that results in frequent occurrences of localized scarcity, regardless of total surpluses or deficits.

Figure 3. Trucks cross the winding riverbed of the Indrawati to deposit gravel at a mining facility surrounded by lowland agriculture. Photo credit: Haris C. Rai.

Natural water supplies in the Indrawati, as is the case throughout the mountainous regions of Nepal, are often far removed from demand; transporting these supplies over long distances through complex geography with piped systems is extremely expensive and energy intensive. Seasonal fluctuations in water availability in the basin are huge; flows are dominated by snow and glacial melt in the dry season until mid-May and then by the summer South Asian Monsoon system (Shrestha 2004). Due to the lack of functional and sufficient storage infrastructure, these interannual fluctuations often have direct ramifications for downstream populations and basin food security.

Many small-scale water use projects operate in the Indrawati, along with two large water infrastructure projects:

- **Melamchi Interbasin Transfer.** This $66 million project will move 170 million liters daily from the Melamchi tributary through a 26-kilometer tunnel to provide drinking water to Kathmandu. Delayed many times due to controversy, construction finally began again in May 2010. The project is expected to reduce the total mean annual flows of the Indrawati by approximately 2% and the Melamchi khola by as much as 60% in the dry season, potentially affecting future dry-season flows (Shrestha 2004; Karki 2005).
- **Indrawati III hydropower plant.** This 7.5 megawatt privately owned run-of-the-river cascade scheme located roughly 100 meters downstream from the confluence with the Lapse Khola has been operational since 2003 (Bhattarai et al. 2002; Karki 2005). The scheme is allowed to divert up to 30% of the river, but field observations indicate that a much higher percentage of the flows are actually diverted in the dry season, leaving little for in-stream uses like fisheries. Currently, only one of three planned plants have been constructed. Even at only 7.5 megawatts, the project is a critical part of a national energy infrastructure plagued by insufficient supply and over-reliant on hydropower as its only energy source (see Box 1).

The smaller-scale water use systems include the following infrastructure:

- **Farmer-managed irrigation systems (FMIS).** Funded in part by the Department of Irrigation (DOI), more than 300 of these systems exist in the basin. They cover areas ranging from 1 to 186 hectares and canal lengths anywhere from 100 meters to 5.6 kilometers. In aggregate, they account for the vast majority of total consumptive water use in the basin, but many are currently in a non-functional state of disrepair (Shrestha 2004).
- **Drinking water systems.** Diverting water from the tributaries and natural springs, these systems serve from 10 to 6,500 people; the majority benefit fewer than 500 people. Many of the 43 systems in the basin in 2000 (Karki 2005) have dried up.
- **Micro-hydro stations.** These stations are often the most feasible local energy supply option in Nepal due to the nation's vast water wealth but poor electricity infrastructure (including supply and transmission). As of 2004, 11 such stations operated in the basin (Table 2).

Table 2. Micro-hydropower stations in the Indrawati.

Name	Capacity (kW)	Location
Gambire/Krishma Thapa	13	Kunchowk
Krishna B. Khadka	14	Musure
Ram B. Basnet	12	Jhangpalkot
Gora B. Thapa	24	Echok – 6
Ghatte Khola MHP	9	Chokati
Handi Khola MHP I	27	Thapalkot
Handi Khola MHP II	26	Thapalkot
Handi Khola MHP III	20	Thapalkot
Handi Khola MHP IV	20	Gunsa
Jyadi Khola MHP	20	Kunchowk
Cha Khola MHP	16	Nayagaon

Source: Adapted from Karki 2005.

Water quality

The most prominent water quality problem in the Indrawati is worsening siltation due to problems in the higher-altitude regions of the Middle and High Mountains: deforestation and degradation (leading to loss of recharge capacity); landslides caused by un-planned road construction; poor soil management techniques associated with slash-and-burn farming techniques, whereby monoculture rotations leave hillsides lacking vegetation for months at a time; and poor terrace construction that can lead to continual loss of topsoil. Gravel and sand mining along riverbeds at the lower altitudes of the Middle Mountains also contributes to erosion problems, especially during high-flow periods of the monsoon, when instead of filtering down into groundwater aquifers, waters will cascade down riverbanks that have been flattened and hardened by the mining process (Sayami 2007). Himalayan rivers are known for having high silt content, but these anthropogenic activities in the basin are contributing to the problem (Karkee 2004).

The Indrawati is relatively unpolluted by industrial activity, which in the basin is minimal. However, increased use of fertilizer and pesticides on agricultural lands has begun to significantly affect water quality downstream at the lower reaches of the Middle Mountains. Eutrophication and algal blooms were evident in lower-altitude commercial agriculture areas during a pre-workshop site visit.

Institutional Arrangements

Because the Indrawati stretches across multiple development districts (regional government boundaries), its natural resources are governed by many institutions—formal and informal, national, regional, and local. The most relevant of these are the Water and Energy Commission Secretariat (WECS), for its role in co-managing national water infrastructure in the basin, and the chief district officers (CDOs) and local development officers (LDOs) of the basin's three districts—Sindhupalchok, Kavreplanchok, and Kathmandu. The latter are responsible for basic district governance and budgetary oversight of all major development activities.

Other important institutions include the district offices of the major ministry departments (forestry, agriculture, livestock, irrigation, and so on); regional and local government district development committees (DDCs) and village development committees (VDCs) (both run by LDOs); and water, forestry, and other user groups. Also important are informal cultural customs and norms like water allocation agreements and Community Forestry User Group (CFUG) management plans. Ultimately, though well-written and defined regulations, policies, and institutions may be in place, their implementation and enforcement, like governance throughout Nepal, remains relatively weak in the face of many challenges (Bartlett et al. 2010).

Legal frameworks

The Water Resources Act of 1992 and Water Resources Regulation of 1993 are the primary governing legislation specific to water at the national level. Their main purposes were to give ownership of the country's water resources to the government, set water use priorities, establish district water resources committees (DWRCs), allow for the creation of water user associations (WUAs) and outline their rights and obligations, and require a license for any major development (Bhattarai et al. 2002; WaterAid Nepal 2005).

The Forestry Act of 1993 and Forest Regulation of 1995 created the legal basis for community forestry management. The Forestry Act of 1993 recognized forestry user groups as legal entities and created five categories of national forest on the basis of primary usage or management goals, including religious, government-managed, or protected (Dahal and Chapagain 2008). Also of note is the Forest Sector Policy of 2000, which required community forestry user groups (CFUGs) to give 40% of their timber sales to the national government.

Another law central to the management of natural resources in the basin is the Nepal Local Self-Governance Act of 1999, which delegated important responsibilities to local government institutions in a decentralization effort. However, local development plans still must be approved annually by the National Planning Commission (NPC) in Kathmandu.

Development and resource management plans

The most recent national development plan is the Three Year Interim Plan, 2007/2008–2009/2010, a 500-page planning document developed by the NPC for all of the relevant national economic sectors. It outlines status quo conditions, including constraints to development, and sets goals for development in each sector (NPC 2007). The plan is also the source for the development scenarios outlined in this report.

The 2005 National Water Plan (NWP) advocates institutional reforms in water resource management. One is allowing river basin organizations (RBOs) to act as WECS sub-units at the local level, theoretically making allocation decisions and centralizing information and data (Government of Nepal 2005). For various reasons, including political instability associated with the country's decade-long civil war (1995–2005) and insufficient capacity, much of the plan has yet to be implemented.

National-level institutions

Though historically in a state of flux, many national-level ministries and organizations have mandates for natural resource management in Nepal. Nine have particular relevance in the Indrawati:

- **Ministry of Forests and Soil Conservation (MFSC).** Responsible for FUGs and administration of national parks.
- **Ministry of Agriculture and Cooperatives (MoAC).** Responsible for all agriculture-related development and various poverty reduction plans.
- **Ministry of Physical Planning and Works (MPPW).** Oversees major strategic transportation networks, urban development, and water and sanitation access.
- **Ministry of Home Affairs (MoHA).** Responsible for all basic governance activities and disaster relief.
- **Ministry of Local Development (MLD).** Coordinates development activities at the regional and local levels, including oversight of LDOs currently in charge of DDCs and VDCs.
- **Ministry of Energy (MoE).** Oversees all hydropower development and operation, including the Indrawati III hyrdropower project.
- **Ministry of Irrigation (MoI).** Supports FMIS with funding and technical expertise.
- **Water and Energy Commission Secretariat (WECS).** The primary water policy arm of the national government, WECS is responsible for updating and implementing the National Water Plan (NWP) of 2005 and coordinating the water resource sector.
- **NGOs.** Many national non-governmental organizations have projects in the Indrawati, including WWF Nepal and the Nepal office of the International Water Management Institute.

Regional/district-level institutions

Multiple institutions have mandates for managing natural resources alongside the departmental offices of the above-noted ministries. The majority of the basin lies in the Sindhupalanchok Development District but part lies in Kavrepalanchok to the south and Kathmandu to the southwest. Development activities in the basin are thus primarily governed at the regional level by the Sindhupalchok DDC and the numerous political sub-units of the villages through village development committees (VDCs), all run by nationally appointed LDOs.[2] The most important resource management institutions at these levels are

- **District Development Committee (DDC).** This committee is responsible for implementation and coordination of all development activities within the district, including administration of the VDCs. It sometimes directly finances water resource development projects.
- **District Water Resources Committee (DWRC).** Created with the 1992 Water Resource Act to coordinate water activities within the district to avoid conflict, its main roles include registration of water user associations (WUAs), providing recommendations to DDC/VDC in resolving water-related disputes, and making recommendations for new irrigation construction.
- **River Basin Organizations (RBOs).** Called for in the National Water Plan of 2005, these organizations are ultimately responsible for continued national decentralization of resource management, making allocation decisions, and centralizing water accounting in the basin.

Village- and community-level institutions

At the village level, the majority of development activities are governed by the VDCs, with some support from international and national NGOs and more informal institutions:

- **Village Development Committees (VDCs).** Basic units of governance at the local level, these committees mediate water-related conflicts and occasionally provide funding for irrigation expansion, micro-hydro, and other small-scale development projects.
- **NGOs.** A number of nongovernmental organizations—both small-scale Nepali institutions and larger international organizations—work at the local level, supporting their own development initiatives or working directly with government in providing infrastructure and developing capacity.

2. DDCs and VDCs are normally run by locally elected committees, but there have been no local elections in a decade, as the national constitutional development process that started in 2006 with the end of civil war, has stagnated. As a result, the capacity of these local institutions has been severely reduced, limiting their ability to effectively manage development progress.

Also of critical importance at the village level are resource user groups. Since decentralization efforts at the national level in the late 1980s and early 1990s, these groups have had an increasingly important role in managing both forests and water resources, often far more effectively than systems managed by formal government institutions (Bastakoti and Shivakoti 2010):

- **Water User Associations (WUAs).** Sometimes formally registered in the district, but responsible for their own funding, these groups handle allocation decisions in the more than 300 farmer-managed irrigation systems in the basin. Inactive for long periods, they primarily regroup to collect rehabilitation costs from system users when repairs are needed to canals, pumps, and so on (Bastakoti and Shivakoti 2010; Bhattarai et al. 2002).
- **Community Forestry User Groups (CFUGs).** Also formally registered in district offices, but unlike WUAs, these groups receive direct technical support from district forestry offices to meet management guidelines and goals. Under the original mandate of forestry management, CFUGs have been instrumental in maintaining the overall environmental quality of the country's forested areas and improving rural livelihoods through community development and poverty reduction (Dahal and Chapagain 2008). Workshop participants repeatedly noted their effectiveness in managing forest resources in the basin.

Informal institutions

Local traditions, customs, and norms continue to play a significant role in rural resource management and livelihoods in the basin, in part because of the constraints faced by the more formal government institutions, but even more so because such institutions have been instrumental in resource management in Nepal for centuries (Bartlett et al. 2010; Bhattarai et al. 2002). In the Indrawati, various informal water allocation agreements dictate, for example, how grain mill owners operate and maintain canals for shared flows with farmers and how water users resolve disputes over allocation during the dry season (Bhattarai et al. 2002).

When asked explicitly about water allocation during scarcity in the dry season, local farmers discussed a variety of current agreements. These included a kind of "first in use" doctrine, similar to that in the American West, whereby upstream users closest to the source with the longest-standing access get priority flows; proportional allocation, in which flows depend on different landholding sizes of upstream and downstream users; and rotational allocation, whereby farmers trade off pumping at hourly intervals. In some cases, a village elder is mandated to allocate water to farmers in the system as equitably as possible, and in other cases, the most powerful users simply take what they wish. This lack of uniformity causes different problems with little chance for redress in many cases. Formal institutions (laws or government bodies) to help resolve disputes are lacking.

Given this context, participants in both the Kathmandu and Chautara workshops highlighted as one of the highest risks to water resources an increase in conflicts with greater water stress in the dry season. They called for both equal distribution mechanisms and enforcement of existing regulations governing prioritized uses. They also recognized that informal institutions—historically sufficient in managing localized, small-scale distribution problems—will no longer suffice in the face of the larger-scale water infrastructure developments and climate change impacts.

Figure 4. The distinctive terrraced agroecosystems of the Middle Mountains. Photo credit: Ryan Bartlett.

DETERMINING RISK

The likely effects of interactions between climate change and development in the Indrawati have been evaluated with the Flowing Forward risk determination methodology. This methodology involves a top-down assessment of impacts from climate change and development, a bottom-up assessment of vulnerabilities of key ecosystems, and a synthesis of these assessments to develop a risk ranking. This ranking is used to prioritize adaptation options.

Top-Down Assessment: Development and Climate Change

Given very limited information on economic growth and development planning in the basin as well as a general lack of hydrological and climate data not only in the Indrawati, but also in Nepal in general, the following climate change and economic growth scenarios are both broad in nature and reflect a significant degree of uncertainty.[3] They do, however, provide a general best estimate of the likely changes to water resources from economic development and climate change.

Economic development

Economic activity in the basin is generally limited to subsistence-based and commercial agriculture. In addition to these activities, sand and gravel mining and national hydropower development are found in the lower reaches of the basin. Projections of future economic growth trends thus focus on these sectors and, given the above-noted data limitations, on two very general scenarios: low growth, a continuation of rates required to keep pace with consumption and population growth rates, and high growth, a doubling of these rates, resulting in significant agricultural and non-agricultural sector expansion. With input from national experts and local users, workshop participants assessed the accuracy of these scenarios and fleshed out their ramifications on water futures (Table 3). Due to time constraints, they focused the vast majority of this analysis on high growth in an effort to outline as conservative a future scenario as possible.

In the high-growth scenario, the indirect effect of regional black carbon will be melting glaciers in the High Himalayas. But the direct human impacts on water resources within the basin will be most substantial in the more populous Middle Mountains, where both consumptive and nonconsumptive water uses and changes to land use are the most significant. Water resource impacts in the High Mountains are primarily limited to religious and mountain tourism, as the region will generally face fewer development pressures due to its geographic isolation from the lower altitudes.

In summary, with high economic growth, changes to normal quantity, quality, and timing regimes in the basin are likely to be significant, and in the lower-altitude regions most conducive to development. Localized incidences of water scarcity and stress, for example, will increase with higher consumptive use for agricultural growth in the Middle Mountains, and ongoing expansion of non-consumptive uses like mining and hydropower will continue to change the hydrograph, increasing the overall variability and intensity of flows in the dry and wet seasons downstream. Road development and land use change will also further affect the flows in the basin, altering the hydrograph to become “flashier” with less vegetation to recharge precipitation and stabilize topsoil.

3. Participants were asked to analyze the accuracy of the scenarios, but ultimately they lacked adequate expertise to attest to their specific validity. Therefore, more general scenarios of “high” and “low” development were used.

Table 3. Impacts of high economic growth on water resources.

Ecoregion	Impact
High Himalayas	**Quantity** – current minimal direct human impact will continue, but indirect melting effects of increased regional black carbon emissions will worsen
	Quality – minimal impact from mountain tourism through water and solid waste pollution
	Timing – changes to seasonal flows from glacial melt due to more rapid melting in the spring months
High Mountains	**Quantity** – limited reduced recharge capacity from deforestation/degradation; some impacts from tourism-based increases in water consumption during dry season, population growth, and agricultural development
	Quality – reductions from deforestation/degradation of alpine forests and rangelands from overgrazing and land-use change; limited impacts from tourism through solid waste and sanitation; increased sedimentation from infrastructure development (erosion from roads)
	Timing – Limited changes to the hydrograph from increased road development, especially when unplanned (lacking proper gradation, drainage infrastructure)
Middle Mountains	**Quantity** – high impact, especially during the dry season with increased consumptive use for irrigation and the Melamchi transfer and a lowering water table from sand and stone mining; overall decrease in per capita availability, increased prevalence of landslides from road development and agricultural land use change
	Quality – high impact on quality from increased use of pesticides and fertilizers; sedimentation from sand and gravel mining
	Timing – high impact during the dry season with increased consumptive use causing changes to the hydrograph
Trans-regional	**Quantity** – high impact (consumptive use for agriculture and irrigation, flow diversions for hydropower, etc.)
	Quality – high impact through increased use of fertilizers and pesticides
	Timing – high impact; long droughts, change in hydrograph from run of the river dams, low flows during the dry season from tourism and agriculture; more runoff and less recharge from sand mining leads to spikes in instream flows from precipitation events, causing floods and landslides and lowering the local water table
	Other – landslides caused by increasing unplanned road development, in both the Middle and High Mountains

Under high economic growth, water quality degradation, particularly in the commercial agriculture-based lowlands, will also become significantly worse. Erosion and sedimentation will increase, along with fertilizer and pesticide use. In addition, outside pressure from ongoing urbanization in Kathmandu will continue to shift the burden of agricultural production to basins like the Indrawati that immediately surround the Kathmandu Valley.

Projected climate change scenarios

Given high natural climate variability across ecoregions and the inherent interannual and decadal complexities of the South Asian monsoon, predicting changes in climate over the short and long terms is an extremely difficult task in Nepal (NCVST 2009; Bartlett et al. 2010; Eriksson et al. 2009; Cruz et al. 2007; Government of Nepal 2005). The general lack of data for the Himalayan region and the uncertainty associated with scaling down general circulation models further compound any attempt to predict specific outcomes. Nevertheless, general trends and some regional models, coupled with community-level observations, provide a basic picture of likely climate changes in Nepal and their impacts in the Indrawati. Workshops in Chautara and Kathmandu were designed to accomplish exactly this task: local users' experiential input would provide Indrawati-specific nuance to the larger trends noted by experts at the national level.

Figure 5. Algal growth is evident among the large-scale agricultural lowlands of the Middle Mountains. Photo credit: Ryan Bartlett.

In general, these trends indicate already rising temperatures that are expected to further increase and at an accelerating rate with altitude. The most significant impacts are evident in the cryosphere of the High Himalayas, and precipitation patterns are expected to become more variable; both total decreases and increases are projected, depending on the model (NCVST 2009; Eriksson et al. 2009; Cruz et al. 2007; RIMS-Nepal 2011). These changes will affect runoff, with increases in the short term and decreases in the long term as a result of rapid deglaciation and seasonality shifts in the monsoon. Huge fluctuations in the frequency and intensity of storm events are projected (Table 4).

Table 4. Climate change trends and water resource impacts in the Indrawati sub-basin.

	Trends	Impacts Identified in Workshops (existing and projected)
Temperature	Significant rise in temperature: • **0.5 to 2.0ºC by 2030** • 1.3 to 3.8ºC by 2060 • 1.8 to 5.8ºC by 2090 Increase in the number of days and nights considered hot by current climate standards Highest temperature increases during winter and pre-monsoon months and at higher altitudes Shift from snow to rain in winter months	*Quantity* – rapid melting of glaciers and snow, higher evaporation, long-term decrease in water storage capacity *Timing* – more precipitation falling as rain with less snow observed at higher altitudes *Other* – vegetation shifts (leaves and needles used for fertilizer falling later in the year, rhododendron flowering earlier in the year); biodiversity losses (medicinal herbs) from drought; increased invasive species prevalence
Precipitation	Wide range of mean annual precipitation changes: • **-34 to +22% by the 2030s** • -36 to +67% by the 2060s • -43 to 80% by the 2090s Increase in monsoon rainfall towards the end of the century: • **-14 to 40% by the 2030s** • -40 to +143% by the 2060s • -52 to +135% by the 2090s	*Timing* – changes in river flow regimes (more in summer/wet season and less during the winter/dry season); shift in the timing of the monsoon; more rapid spring snow melt; uncertain and unpredictable water flows, changes in flow patterns and hydrographs *Quantity* – drying up of spring sources due to drought
Runoff	**Higher downstream flows in the short term**, but lower in the long term due to retreating glaciers, melting snow and ice **More variability**, from shift in seasonality of the monsoon; i.e., later onset and termination dates; and long periods of drought followed by intense storm events	*Quantity* – reduction of dry season flows through more prevalent and longer duration droughts; flash floods in wet season that cause river bank erosion; total drying out of streams in the dry season *Quality* – water quality deterioration from flows reductions and water chemistry changes (increased biota, changes to dissolved oxygen, etc.)
Extreme Events	**Increased frequency and potency of floods and droughts**, as long periods of drought are followed by intense storm events **Increased frequency of glacial lake outburst floods (GLOFs)** with glacial melting and retreat	*Quantity* – greater intensity and frequency of landslides, floods and droughts: loss of life and properties, displacements, environmental degradation *Other* – increased prevalence of forest fires due to drought, loss of soil moisture

Water futures

With changes from development and climate change separately identified, the next step in the assessment is to determine the most likely combined impacts on water resources under both scenarios, thereby establishing the key baseline components of risk. Table 5 shows the highest-priority combined effects of both development and climate change on water futures (changes to quantity, quality, and timing) throughout the basin.

Each group of workshop participants identified the same changes and primarily considered universal key determinants of quantity, quality, and timing. Workshop participants in the basin in Chautara highlighted more indirect water and agriculture impacts—increased pests and disease and loss of native plant and fish species, biodiversity, and soil productivity—rather than basin-wide impacts like melting of the High Himalayan glaciers. Given the different backgrounds of local- and national-level participants and the large contingent of farmers and water users in Chautara, this focus is not surprising.

Bottom-Up Assessment

Once the top-down assessment identified the highest-priority changes to water resources in the Indrawati according to development and climate scenarios, the next critical step was to analyze the inherent vulnerability of the basin's key ecosystems and economic sectors.

Ecosystem vulnerability

According to the Flowing Forward methodology, vulnerability is determined by four key ecological criteria: detrimental non-climatic pressure, defined as the extent to which the ecosystem faces anthropological pressures; natural variability, whether natural disturbance events like droughts and floods occur within the ecosystem with regularity (with greater frequency translating to greater resiliency); refugia, the extent to which the ecosystem provides a refuge from climate shocks for species through different microclimates; and connectivity, the degree to which an ecosystem has "corridors" that allow for species to migrate within or across other ecosystems. Workshop participants used these four main criteria to determine the vulnerability of the key ecosystems (Table 6).[4]

Table 5. High-priority water futures in the Indrawati.

	Impacts
Quantity	**Permanent water stress** from decreased water availability and reduced storage in the dry season
	Increased conflict from water stress
	Drying up of water sources due to increased consumptive use and droughts
	Glacial retreat and reduced snowpack compared to the past
Quality	**Wetland degradation and biodiversity loss** from increased tourism pressure
	Increased turbidity and deterioration of water quality from overall quantity reductions in the long term (high consumptive use, especially during the dry season, and glacial retreat)
	Deterioration from siltation and land use change resulting from unplanned roads and development
	Land/water pollution from chemical fertilizers and pesticides
Timing	**Unreliable hydroelectric production** due to inconsistent flows from increased demand and greater variability from climate shifts
	Extreme events; greater potency and frequency of floods, droughts, and landslides
	Landslides caused by unplanned roads and other land use change
	Changes in cropping patterns due to unreliable and erratic flows
	Seasonality shifts; too much water from July to September and too little January to February
Other	**Decreased agricultural productivity**
	Decreased food security due to higher demand with lower crop productivity
	Increased poaching of high value species
	Land and forest degradation from land use change and forest fires
	Forest fires
	Loss of aquatic fish species; reduced numbers in higher altitudes and extinction in lower regions

Table 6. Vulnerability of key ecosystems using the Flowing Forward criteria.

	Climate Resilient Ecosystem Qualities				
Ecosystem	Detrimental Anthropogenic Impact	Natural Variability	Refugia	Connectivity	Average Vulnerability
Rangelands: pasture, open grazing	High	Medium	Medium	High	High
Wetlands/lakes and ponds	Medium	Medium	High	High	High
Forest: mixed hardwood, broadleaf forest	High	Medium	Low	Low	Medium
Freshwater (across all regions): rivers, streams	High	Low	Medium	Low	Medium
Agroecosystems (across all regions)	Null	High	Null	High	High

Table indicates level of vulnerability, such that 'low' (yellow) means less vulnerability in terms of the criteria and 'high' (red) means more vulnerability. 'Null' (used only for agroecosystems) signifies criteria that do not apply. Results are from the national-level workshop in Kathmandu only. See Appendices B and C for local-level vulnerability determinations.

All key ecosystems in the basin were determined to have either medium or high vulnerability.[5] On the basis of the above-noted criteria, the most vulnerable ecosystems were rangelands and wetlands in the High Mountains, mixed broadleaf forests of the Middle Mountains, and agroecosystems across the basin.

Rangelands in the High Mountains were determined to be highly vulnerable due to significant human impacts, particularly land degradation from overgrazing of livestock and lack of connectivity, whereby landscape patchiness impedes species from moving through the system in response to drought, flood, and fire. These rangelands are also highly vulnerable because they

4. Due to time constraints and the limited ecology backgrounds of participants, a simplified version of this step in the methodology was used in the workshops in Chautara. Only two of the four criteria, anthropogenic impact and natural variability, alongside an additional metric, the degree to which local populations are dependent on the ecosystem (used to explore direct linkages at the local level between ecosystem services and livelihoods), were used to determine rankings of vulnerability.
5. This outcome highlights a potentially inherent bias in the selection process, as participants may have subconsciously identified more vulnerable ecosystems at the outset.

Figure 6. The extremely low outflow of the Indrawati III hydropower plant, shown here in the dry season (spring 2010). Photo credit: Heather Hosterman.

are accustomed to neither such disturbances nor to wide natural variability. Wetlands were found to be similarly vulnerable. Their minimal connectivity limits their capacity to provide refuge for species during extreme climatic events that only intermittently occur, further reducing their resiliency.

Because agroecosystems are manmade, at least two of the four ranking criteria, anthropogenic impact and refugia, do not apply. On the basis of the remaining criteria, these systems were found to be highly vulnerable. They are unaccustomed to high variability and natural disturbances. Moreover, they are not well connected. Small average landholdings and a general lack of irrigation in the basin create a fragmented and thus less resilient system.

Notably, rivers and streams across the three ecoregions were deemed to have only medium vulnerability. Although they are highly affected by the detrimental anthropogenic effects of agriculture, hydropower, and development, they remain fairly robust, are accustomed to regularly occurring disturbances like droughts and floods, and are relatively connected, despite the Indrawati III national hydropower dam and micro-hydro dams. However, at the local-level workshops, local water users ranked streams and lakes in the Middle Mountains as highly vulnerable to anthropogenic impacts from fertilizer and pesticide use.

Economic sector vulnerability

Given the direct dependency of local populations on the basin's ecosystem services, understanding how ecosystem vulnerabilities relate to vulnerabilities of key economic sectors is important. The largest and most important sector to the Nepali economy is agriculture. The next most important sector is hydropower, the primary energy source for the basin (and Nepal). The hydropower potential of the larger Koshi Basin that houses the Indrawati is massive.

Hydropower

Regarding hydropower development in the Indrawati basin, climate change is likely to compound existing vulnerabilities and add significant new impacts, such as the following that were identified during the workshops:

- **Increased inter- and intra-annual variability of stream flow** (increased during monsoon season, decreased during dry season) due to glacier melt and changing precipitation patterns.[6] Particularly during the dry season, reduced flows could make hydropower generation (and planned water transfers) from the Indrawati III dam and micro-hydro plants more unreliable.
- **Increased sedimentation and more frequent landslides** due to extreme rainfall events and flooding during the peak runoff period as well as continued soil erosion linked to agricultural practices, unplanned road development, and land use changes in upstream areas. Sediment and landslide-related damage to hydropower facilities may increase maintenance budgets and shorten operating life, making hydropower a less attractive option to investors.

Box 1. National hydropower sector vulnerability.

Nepal gets about 90% of its energy from hydropower, yet it has harnessed less than 2% of its economically feasible hydropower potential, which is estimated to be 45,610 megawatts (WECS 2011). Currently, electricity reaches only 15% of the population, primarily in urban areas, but also in some rural areas through micro- and small hydropower. Because supply meets only 1% of demand (Raksakulthai 2003), rolling power cuts have been implemented in recent years. Meanwhile, demand is growing at about 11% annually, and the National Electricity Authority projects that demand will increase fourfold in the next 14 years (WECS 2011; Raksakulthai 2003). Thus, major plans for hydropower expansion (both for domestic use and export to neighboring countries) are central to Nepal's overall energy strategy. The government has targeted 2,035 megawatts in new development by 2017 and 4,000 megawatts by 2027 just to meet domestic demand (WECS 2011).

In most climate change assessments for Nepal, water is considered the most vulnerable sector, given projected impacts from glacier retreat, expansion of glacial lakes, and changes in the seasonality and intensity of precipitation. Hydropower is viewed as an "area of great concern" with regard to climate change, and the sustainability of both present and planned hydropower and water infrastructure projects is a major concern (Alam and Regmi 2004, 34). As WECS (2011, 1) points out, "the spatial and temporal distributions of freshwater are highly sensitive to climate change." Although existing climate variability is starting to be incorporated into project design, future climate risks are only infrequently considered.

Agriculture

Little specific information on the avenues of agricultural vulnerability to climate change in the Indrawati basin is available, but positive and negative effects are indicated. Temperature increases may, for example, help cereal production expand in hilly and mountainous regions. DSSAT modeling has shown that rice, wheat, and maize production and yields may increase (Malla 2008), in part through a decrease in crop damage from extreme cold and frost. Currently, farmers grow several crops per year, depending on altitude; an additional crop may become possible at higher altitudes (Malla 2008). However, vector-borne livestock diseases and crop pathogens like rusts and blights may shift to higher elevations as well. Some of the commercial crops that may be expanding in the Indrawati basin (like tomatoes) are vulnerable to pest outbreaks. Even with potential yield increases and additional cycles, major water resource-based constraints would remain.

Water-related issues are likely to be more problematic for agriculture than temperature-related ones. Increased variability of precipitation and seasonal water availability could severely affect farm livelihoods (Raksakulthai 2003). For example, more frequent droughts are expected from November to April due to glacier retreats, higher temperatures, less winter precipitation, more evapotranspiration, and decreased soil moisture levels. "Such droughts or very low rainfall levels at critical points in the development phases of winter and spring crops can dramatically reduce crop yields and livestock numbers and productivity," writes Rai (2007, 94). Likewise, increased flooding due to changes in precipitation and hydrological cycles could lead to localized crop damage, compounded in some cases by soil erosion and land degradation, especially in the lowland areas of the Middle Mountains.

Local observations from elsewhere in Nepal indicate that agricultural production in hilly and mountainous areas is becoming more uncertain. Nepal's National Adaptation Plan of Action (NAPA) technical working group reports that

6. As Raksakulthai (2003) notes, "interannual variability [c]ould affect the operating efficiency of plants. For example, a study on the dependability of flow throughout the year in the Bagmati River shows a long-term average of 21.1 m^3/sec 92.3% of the time. Under the scenario of doubled CO_2, however, it will be only 7.43 m^3/sec. The current range of the Bagmati is 316.26 m^3/sec, which is projected to increase to 810.37 m^3/sec. This poses considerably more complexity for hydropower planners and engineers in maintaining electricity generation throughout the year. It will require additional considerations in plant design to accommodate the greater range of runoff."

> Inconsistent productivity of winter potatoes in the hills and summer season potatoes in mountain region are associated with increasing uncertainty in the form, timing and intensity of precipitation. In mid hills, climate change impacts are observed on maize and maize-based ecosystems. Likewise, in mountain and mid hill regions, climate change impacts are observed on fodder and forage production as a result, animal herders are gradually decreasing their herd size (Government of Nepal 2010, 43).

In a community vulnerability assessment carried out for WWF Nepal in the Langtang National Park buffer zone, in the upper Indrawati basin and the neighboring basin to the west, local people reported declines in cereal crop production due to water scarcity, changing precipitation patterns, increased drought, and the appearance of invasive species (RIMS-Nepal 2011). Similar community-based monitoring of climate change impacts (also see Dixit et al. 2009) on agricultural systems in the Indrawati basin would be a low-cost strategy to track climate change impacts on rural livelihoods and land use patterns and to identify successful adaptation options.

Box 2. National agricultural sector vulnerability.
Although the magnitude of climate change risks for Nepalese agriculture is the subject of debate, concern about potential impacts on overall production and food security is considerable. Overall, the sector is thought to have fairly high exposure and moderate sensitivity to climate change. Few direct impacts are expected, but indirect impacts, especially those related to water resources, may be considerable (Agrawala et al. 2003; Bartlett et al. 2010). The Agriculture and Food Security team working on Nepal's National Adaptation Programme of Action highlights some of these impacts: changes in precipitation type, frequency, and intensity affecting irrigation and cropping patterns, changes in agro-ecological zones (expansion of cropping seasons/areas, shifting disease/pest/parasite patterns, and changes in crop-water use due to temperature increase), and implications for livestock (result of changes in grazing and fodder provision) (Government of Nepal 2010).

Synthesis

The final step of the Flowing Forward risk assessment is to combine the water resource impacts outlined for development and climate change scenarios in the top-down assessment with the ecosystem and economic vulnerabilities identified in the bottom-up assessment. This step results in a final ranking of risk for each of the identified major impacts on water resources, allowing decision makers to prioritize potential adaptation responses. Table 7 shows the "high risk" impacts of water futures, by ecosystem.

Some differences in risk among the three main ecoregions are clear, but some risks are basin-wide. Among the latter are water quality reductions in wetlands and other freshwater ecosystems in both the High and Middle Mountains. These reductions are listed alongside similarly universal supply concerns of glacial melt, reduced availability, increased demand, and decreased food security.

Table 7 also reflects some of the ranking differences between the national- and local-level workshops. Whereas the national-level prioritization process generally resulted in more basin-wide, regional-scale risks like permanent water stress, decreased food security, and conflict over water availability, the local-level process resulted in attachment of a higher priority to agricultural water use issues like shifting growing seasons, soil fertility loss, and land and water pollution. National experts thus provided the larger skeletal framework of risk that was then filled in with much more detail by local-level farmers and water users, who have a much better understanding of the day-to-day resource management issues on the ground.

National experts deferred to local inhabitants when unsure about specific risks and vulnerabilities, and especially when prioritizing responses. The field workshops were critical not only in detailing an additional layer of risk at the local level (the local bureaucrats' workshop and the local water users' workshop in Chautara prioritized risks somewhat differently), but also in determining priority risks and their consequent responses. The top five overlapping risks were drying of spring sources, forest degradation and fire, biodiversity loss, landslides, and river bank erosion from floods. The consensus was that drying of spring sources is the most important risk.

Table 7. Final ranking of risk.

Ecoregion	Ecosystem	High Risk Impacts of Development and Climate Change
High Himalayas (above 5,000 m)	Cryosphere: glacier, snow, permafrost	Glacier retreat
High Mountains (3,000–5,000 m)	Rangelands: pasture, open grazing	Increased degradation due to changes in livestock migration
	Alpine forests	Forest fires
	Wetlands/lakes and ponds	Wetland degradation: biodiversity loss, water quality reductions
		Drying of spring sources
		Water pollution and human waste
		Landslides
Middle Mountains (1,200–3,000 m)	Forests: mixed hardwood, broadleaf	Forest degradation (soil loss, vegetation shifts, land use change)
	Wetlands	Biodiversity loss
	Region as a whole	Permanent water stress from decreased water availability and reduced storage
		Drying of spring sources
		Increased poaching
Trans-regional (cut across multiple ecoregions)	Freshwater: rivers and streams	Water quality deterioration (increased turbidity)
		Decrease in water availability
		Increased demand for water
		Landslides
		River bank erosion from flooding
		Conflict over water availability
	Agroecosystem	Decreased crop productivity
		Land and water pollution from increased pesticide, fertilizer use
		Shifts in cropping patterns (rice to millet and wheat, difficulty timing rice transplantation)
		Soil fertility loss
		Decreased food security

RESPONDING TO RISK

The final goal of the workshops was to develop a comprehensive list of potential adaptation options to address vulnerabilities, impacts, and risks. The feasibility of these options depends on the actual capacity of institutions in the basin to implement projects or policy changes. The workshops largely confirmed the existing literature on this capacity, which highlights inherent constraints in Nepal's formal institutions that limit effective governance and prevent the basic implementation of resource management laws and regulations (Bhattarai et al. 2002; Bartlett et al. 2010; FAO 2003).

Adaptive Capacity

The adaptive capacity assessment focused on policies, institutions, and infrastructure, organized along local, regional, national, and international institutional divisions.

Policies

Participants largely confirmed the results of previous studies of resource management and adaptive capacity in Nepal. They found that capacity to be generally low at the local and regional levels, with the exception of Community Forestry User Group agreements and policies. They also pointed to the gap between Nepal's NAPA and its implementation at the local level. Poor implementation was a commonly cited justification for low rankings of adaptive capacity.

Workshop participants at the local level outlined more specific problems associated with policy implementation. For example, due to a lack of legally recognized allocation guidelines or regulations during instances of water scarcity, each water user association essentially dictates its own allocation mechanisms, often leading to inequitable outcomes. Even when regulations exist, participants noted that users often do not know what they are or who is responsible for their implementation. Simple questions of what water infrastructure is permitted, which government agencies approve projects, and how fines are structured are not easily answered. One reason noted by participants and identified in at least one study (Bartlett et al. 2010) is the lack of staff and budgets to monitor and oversee regulations.

Institutions

Participants found institutional adaptive capacity higher at the national and international levels than at the regional and local levels. Some participants argued that the overall high resilience of local populations was justification for concluding that local adaptive capacity is high. Ultimately, participants agreed that—as measured by technical expertise, financial resources, and decision-making power—adaptive capacity increases from the local to the international level (Table 8).

Table 8. Institutional adaptive capacity.

Level	Capacity			Overall Adaptive Capacity	Notes
	Financial	Institutional	Human		
Local (VDCs, WUAs, etc.)	Low	Low	Low	Low	Local populations determined resilient, but overall institutions have insufficient resources and decision making power
Regional (DDCs, Ministry Depts, etc.)	Medium	Medium	Low	Medium	Less vulnerable than the local level due to more available resources, but still lacking sufficient technical expertise
National (Gov't Ministries, local NGOs, etc.)	Medium	Medium	Medium	Medium	Slightly more technical expertise, but still lacking in financial resources and decision-making power
International (World Bank, ADB, NGOs, etc.)	High	High	High	High	Much more available resources across the board, from technical expertise to funding, relative to local and national institutions

Overall adaptive capacity measured as a function of three factors financial (how much access the institution has to monetary resources), institutional (how empowered the institution is to make decisions and allocate funds), and human (whether the institution has sufficient technical expertise to implement its mandate). Note: capacity is color-coded based on vulnerability. Low capacity is red, as it translates to high vulnerability; high capacity is coded yellow, as it translates to low vulnerability.

Infrastructure

Participants determined that all infrastructure in the basin had either low or medium adaptive capacity, mainly due to poor operations and management and the general ineffectiveness of both policies and local government institutions. In general, they found that larger-scale and government-managed systems—including the two largest water infrastructure projects in the basin, the Indrawati III national hydropower facility and the Melamchi Interbasin Transfer—have somewhat lower adaptive capacity than the smaller-scale micro-hydro, drinking water, and farmer-managed irrigation systems directly under user group/association control. Participants stated that drinking water systems managed by water user groups were more effectively operated than those paid for by donors and run by government institutions. Given that they considered the adaptive capacity of CFUGs and WUAs to be high, this determination is not surprising.

Adaptation Options

The final goal of the workshops was to develop an initial list of adaptation options that both prioritizes the highest-risk impacts and accounts for capacity deficiencies in policies, institutions, and infrastructure. Ideally, these options would include three types of infrastructure: "hard" (actual physical construction), "soft" (technical, human expertise, capacity), and "natural" (bioengineering,[7] afforestation). Table 9 shows the options for responding to the highest-risk impacts, organized by impact and ecosystem, as chosen by the workshop participants. Additional options related to the hydropower and agriculture sectors were identified following the workshops; these are summarized in the final section of this report. For a complete list of impacts and options identified during the workshops in Kathmandu and Chautara, see Appedices A and B.

The Flowing Forward process required participants to determine adaptation options specific to each individual identified risk, but several themes emerge when the options are analyzed through the lens of the three infrastructure types. The "soft" options, alongside technological solutions, dominate the list. Participants repeatedly criticized the effectiveness of resource management institutions at multiple levels of the bureaucracy. With expert participants in Kathmandu

7. Bioengineering in this context is defined as manipulation of the natural environment through, for example, planting of different tree species to stabilize slopes where soil erosion and landslides are a major problem.

noting inefficiencies at the larger national scale and local water users in the basin drawing attention to failures at the local level, this focus was not surprising.

Participants also identified very similar adaptation options for very different risks. In some cases, capacity building, awareness raising, further research, better implementation of existing policies and regulations and other policy reforms, and infrastructure improvement and development (hard and natural) were all identified for one high-risk impact. Participants focused on all three types of infrastructure in an effort to develop "best" adaptation options. They indicated a need for hard and soft infrastructure and for expanding the capacity of the institutions responsible for the infrastructure's management.

Because on-farm projects and institutionally focused interventions exist at opposite ends of the macro/micro spectrum, the scales at which adaptation options would be implemented must be considered. The options for responding to the risk of decreased food security perfectly exemplify this need. Policy reforms for restoring fertilizer subsidies are a national policy question requiring national institutional involvement, whereas water-use efficiency technology and agricultural best-management practices can be applied at the farm level by locally focused institutions.

Different risks also require different temporal response scales. Deglaciation caused by rising temperatures, for example, has much longer-term impacts than droughts and floods caused by increasing seasonal fluctuations in the monsoon. Strategic planning for risks that will play out over the longer term and development of projects that will reduce vulnerability now are both critical. Water-use efficiency techniques and technologies like small-scale storage ponds and drip irrigation, for example, can be employed immediately at the household level, while strategic planning through relevant national and district institutions like the DDCs and WECS can be used to determine the most viable agricultural lands for commercial production in the longer term.

Implementation in both the short and long terms will also require better coordination and integration across geographic scales, because climate impacts will occur across institutional boundaries. National workshop participants explicitly highlighted the need for institutional integration mechanisms, including some called for in the 2005 National Water Plan. They noted that the work of existing water resource management institutions could be integrated through development of river basin organizations and other integrated water resource management techniques. However, this task will require significant capacity development of agricultural policy and planning institutions at the national and district levels to overcome numerous existing constraints to effective resource management.

MOVING FORWARD

Reducing the vulnerability of ecosystems, local livelihoods, and economic sectors in the Indrawati to the impacts of climate change will require decades of consistent and concerted effort from a wide spectrum of stakeholders within the basin and across Nepal. Despite the scarcity of data on and the general lack of public knowledge relevant to many resource management questions, the revised Flowing Forward methodology allowed for a robust rapid analysis because it included consultation with a wide range of stakeholders, including local water users—a first for Flowing Forward. These users proved critical in helping to fill in information gaps, and more importantly, helped steer the process toward bottom-up, locally based adaptation solutions.

Next Steps

The five highest-ranked risks determined by local water users—drying of spring sources, forest degradation and fire, biodiversity loss, landslides, and river bank erosion from floods—should be the key focus areas of the adaptation process. Adaptation-specific resources should be directed, in particular, at spring sources, given their high prioritization in all three workshops at the national and local levels. Relevant stakeholders, resource managers, and planners in the basin should focus on the "best" adaptation options—a combination of hard, soft, and natural infrastructure—that address each of these five priority risks. The following are some initial recommendations for immediate next steps.

Table 9. Adaptation options for highest-risk impacts from all workshops.

Ecoregion	Ecosystem	High Risk Impacts	"Best" Adaptation Options
High Himalayas (above 5,000 m)	Cryosphere: glacier, snow, permafrost	Glacier retreat	Baseline data collection; research
High Mountains (3,000–5,000 m)	Rangelands: pasture, open grazing	Increased degradation due to changes in livestock migration	Land use zoning, existing policy enforcement
	Alpine forests	Forest fires	Policy enforcement; protected areas and buffer zones around forests; fencing, forest management and fire line construction; early warning system
	Wetlands/lakes and ponds	Wetland degradation: biodiversity loss, water quality reductions	Identification of critical wetlands; apply for RAMSAR site classification and develop site management plan; capacity building to improve regulation of the sand and gravel mining industry; soil bioengineering; river training
		Drying of spring sources	Forest, water, spring conservation; awareness raising; source protection; catchment ponds and artificial recharge ponds; afforestation
		Water pollution and human waste	Awareness raising; implementation of existing anti-pollution laws
		Landslides	Soil and water conservation act and other regulations; awareness and advocacy programs; forest and land use management improvements; embankments (gabion walls) and bioengineering; planned road development
Middle Mountains (1,200–3,000 m)	Forests: mixed hardwood, broadleaf	Forest degradation (soil loss, vegetation shifts, land use change)	Policy enforcement; protected areas and buffer zones around forests; forest management and fire line construction
	Wetlands	Biodiversity loss	Reduced pesticide use; source conservation; limitations on sand and gravel mining
	Region as a whole	Permanent water stress from decreased water availability and reduced storage	Water, forest, wetland conservation and restoration; afforestation; rainwater harvesting; spring source conservation; water storage structures (reservoirs and tanks)
		Drying of spring sources	Forest, water, spring conservation; awareness raising; source protection; catchment ponds and artificial recharge ponds; afforestation
		Increased poaching	Protected areas, improved monitoring of protected species (cameras)
Trans-regional (cut across multiple ecoregions)	Freshwater: rivers and streams	Water quality deterioration (increased turbidity)	Capacity building for local level and river training
		Decrease in water availability	Best agricultural management practices; water and soil conservation
		Increased demand for water	Best agricultural management practices; water and soil conservation
		Landslides	Soil and water conservation act and other regulations; awareness and advocacy programs; forest and land use management improvements; embankments and bioengineering
		River bank erosion from flooding	River training; enforcement and implementation of existing watershed and forestry regulations
		Conflict over water availability	Equal distribution mechanisms; prioritization of use; source and forest protection; drinking water and irrigation infrastructure
	Agroecosystem	Decreased crop productivity and soil fertility loss	Soils studies; promotion of organic farming; agricultural subsidies; technical capacity building
		Land and water pollution from increased pesticide, fertilizer use	Organic farming; awareness raising
		Shifts in cropping patterns (rice to millet and wheat, difficulty timing rice transplantation)	Research on climate change effects of crop yields, necessary changes in inputs (seed, land preparations, fertilizer, pesticides, water, etc.)
		Decreased food security	Policy reforms to restore subsidies for farmers (for fertilizer); organic farming, and water use efficiency technology

Overarching goals

- **Expand the knowledge base.** High-capacity national-level (and internationally funded) NGOs like WWF Nepal should work with WECS, national ministries, district department offices, and local water user groups to expand knowledge about the specific climate risks faced in the basin, especially in data- and information-scarce regions. Supporting the Department of Hydrology and Meteorology to secure funding for (and establish) additional electronic information flows and climate monitoring stations in the basin, for example, will go a long way toward this end, as will qualitative assessments like this report (and recently finished work in Langtang National Park; see RIMS-Nepal 2011).
- **Support institutional integration.** NGOs should work with all relevant actors in resource management and policy at the district level to improve implementation, oversight, and enforcement of existing laws and regulations. The 2005 National Water Plan, in particular, provides a platform on which many national and local actors can collaborate on resource management. WECS and WWF Nepal are doing some of this work in the Dudh Koshi sub-basin, but increased funding to further develop the capacity of institutions like river basin organizations (RBOs) and integrated resource management committees (IRMCs) is critical to the long-term adaptation process. Resource management-focused NGOs are particularly well suited to facilitate educational and capacity-building workshops directed, for example, at local departmental offices (forestry, agriculture, irrigation, WECS, and so on) for more integrated management of local resources within the context of adaptation.
- **Collaborate with other national adaptation initiatives.** There are numerous ongoing adaptation initiatives throughout Nepal, including in other vulnerable mountainous regions similar to the Indrawati sub-basin. The latest iteration of the National Adaptation Plan of Action (NAPA) process, where adaptation plans are developed at the local level to coordinate with the NAPA (called local adaptation plans of action, or LAPAs), is one such initiative. With an explicit focus on better coordination and integration across local, sectoral, and national institutions, and merging top-down and bottom-up planning, the LAPA process supports the above two goals and provides a natural framework for next steps in implementing the adaptation solutions outlined this document. Some of these steps in the LAPA process include detailed vulnerability and impact mapping and adaptation planning at the local level, developing an institutional structure for operationalizing plans, pilot implementation at the VDC and DDC level, and monitoring and review of the pilots (see Regmi and Karki 2010 for a more detailed description of the LAPA process). Piloting a LAPA in the Indrawati would serve as an ideal opportunity for Nepali government institutions like WECS and the Ministry of Environment to begin the collaboration that is critical to larger, longer-term strategic adaptation. High-capacity NGOs with expertise in the basin would be ideally suited to facilitating such collaboration.

Specific Interventions

- **Follow-up with local workshop participants.** Critical to longer-term goals of the adaptation process will be ensuring the continued participation of local stakeholders, especially those involved in the Flowing Forward workshops. Follow-up workshops should delve further into the highest risks and related adaptation options. Particular attention should be paid to outlining specific plans for addressing each risk, including prioritizing locations for interventions, training for on-farm technical solutions (including those identified during the Chautara workshops like catchment and recharge ponds), and education of best management practices. Developing LAPAs for the basin could be one way to guide these next steps.
- **Develop a spring source conservation plan.** A critical step in addressing this highest-priority risk will be to map the exact locations of important springs in the basin, especially those in the Middle Mountains that are most vulnerable to anthropogenic and climate risks. NGOs can then work with local users groups (WUAs, CFUGs, FMIs) and formal institutions (departments of forestry, irrigation, agriculture, and livestock) to develop a sustainable management and conservation plan to increase the springs' resiliency. Bringing these groups together to develop such a plan will also advance the goal of integrating the efforts of resource management entities.
- **Educate and raise awareness among resource managers about climate change impacts and adaptation.** NGOs should work with relevant local resource management institutions, including user groups like WUAs; farmers' and drinking water groups; CFUGs; and formal government offices like WECS, DDCs, VDCs, and Departments of Irrigation, Agriculture, Forestry, and Soil and Watershed Conservation in holding workshops and training sessions on changes in the basin under new climate regimes. These sessions should focus particular attention on the intersection of forestry, agriculture, and water resources interventions, namely soil/slope stabilization (including afforestation of unstable, landslide-prone areas and other bioengineering), fire resilience, and planned road construction (embankments), all of which address the five highest risks identified above. NGOs could then facilitate the

Box 3. Hydropower and agriculture sector adaptation in the Indrawati.

Hydropower

Most importantly, perhaps, the predicted increase in the variability of seasonal flows should be incorporated into the planning, design, and operation of existing and planned hydropower facilities. Dam design should seek to incorporate future reduced capacity, and the possibility of multiple "units" (cascades) should be explored. Future hydropower facilities could be sited in less vulnerable locations through better catchment-level spatial risk mapping (Agrawala et al. 2003).

Mini and micro-hydro facilities, already important in the Indrawati, may be preferable to large facilities as they could be less maladaptive. However, mini- and micro-hydro facilities may not meet future demand or be climate-adaptive, depending on where and how they are constructed. Alternative sources of energy and better demand-side management are an important part of the larger debate on energy production in the Indrawati.

Addressing environmental trade-offs relating to hydropower will also be a necessity for adaptation planners. Currently, monthly environmental flow requirements are theoretically enforced for dam operators (50% of monthly natural flows must be released downstream). Those flow requirements, which are meant to meet the minimum needs of fish and other aquatic biodiversity, are, however, not always enforced and may be increasingly viewed as an obstacle to future hydropower development (WECS 2011). Yet protecting watersheds and ensuring minimum flows are important adaptation strategies for the rivers as well as for local communities dependent on them for other ecosystem services. In fact, "softer" responses like those identified by workshop participants (such as afforestation of upland catchments and disaster risk reduction with communities) may be a step toward more adaptive hydropower development.

Lastly, better and more transparent monitoring of flows, sediment loads, and other critical climate and hydrological data will help relevant government agencies as well as private-sector investors, dam operators, local communities, and other stakeholders understand how climate change is affecting water resources in the Indrawati—and what the impacts mean for planned infrastructure development, including major projects such as the Melamchi Water Transfer.

Agriculture

In addition to the agriculture-focused adaptation options identified by workshop participants, several on-farm adaptation options as well as priority areas for future research may be worth exploring with the support of relevant government agencies (such as the Nepal Agricultural Research Council), NGOs, and other partners. These options include

- Drought-resistant seeds and varieties of existing crops
- Integrated pest management to deal with new pest-related issues
- Low-tillage methods and improved terracing to reduce soil erosion
- Localized water conservation and storage systems
- Spatial risk mapping of existing agricultural areas
- Community-based monitoring of climate change impacts
- Basin-level modeling of climate/water/agriculture interactions
- Participatory research on crop suitability and seasonal water availability

development of adaptation-focused management plans by various groups as part of a LAPA pilot, with support from these same departments and national-level ministries like environment, agriculture, irrigation, and local development, among others.

These steps should provide a solid starting point for increasing the resilience of both local livelihoods and ecosystems. Collaboration by policy makers, resource managers, and local water users will be critical in establishing short-, medium-, and long-term goals for reducing vulnerability. Box 3 contains additional ideas for adaptation options related to the agriculture and hydropower sectors in the Indrawati. For additional, comprehensive lists of the impacts identified during each workshop session and their recommended responses from participants, see appendices.

REFLECTIONS ON METHODOLOGY

In implementing the rapid assessment Flowing Forward methodology, the workshops provided a unique opportunity for a diverse group of basin stakeholders—government institutions, civil society, and the private sector—to discuss shared issues and offer high-quality inputs. The methodology proved to be a particularly useful tool for evaluating climate change vulnerability at the nexus of human and natural systems. Nevertheless, some changes could be made to aid future application of the methodology.

Workshop Participants

The assessment could have benefitted from additional participation by the planning sector at the national level and by inhabitants from the higher reaches of the High Himalayas at the local level. Macroeconomic and development planning expertise was particularly under-represented. Individuals from the government's National Planning Commission or from the international financial institutions that are involved in national planning from the donor side would have allowed for a much more rigorous analysis and development of likely economic growth scenarios in the Indrawati. These individuals were invited but unable to attend.

Agenda

On the basis of recommendations of previous Flowing Forward case studies, workshops at the national level in Kathmandu were held over the course of two days instead of one. Another half day would allow for a more profound analysis. In cases like the Indrawati, in which background data, existing research, and basin-specific expertise (at least at the national level) are so limited, a slightly longer agenda could allow for the filling of information and knowledge gaps.

At the local level, the one-day workshop agendas proved burdensome for busy local bureaucrats. For local water users and farmers, who provided some of the most detailed and useful inputs, a lengthier agenda may be feasible.

Lastly, given more time, the assessment would have benefitted from additional workshops in the field. Input from inhabitants of the higher altitudes of the High Himalayas and High Mountain regions was somewhat lacking. More local-level workshops in each of the three main ecoregions would be ideal.

Local versus National

As the first Flowing Forward case study with a field workshop component, the Indrawati case study had no precedent for translating a complex methodology directed at national-level experts to local-level participants with no formal training in resource management and science. Guidelines for this task would ensure congruity of the local- and national-level assessments and facilitate application of the methodology in catchments and sub-catchments throughout Nepal.

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APPENDIX A: NATIONAL-LEVEL WORKSHOP IN KATHMANDU

Table A-1. Key ecosystems in the basin and their significance.

Ecosystem	Why is it important? (e.g., to livelihoods, ecosystem services, cultural/religious values)
Cryosphere: glacier, snow, permafrost	Source of freshwater, storage for water towers (regulating flows), tourism, cultural/religious importance
Scree/rugged mountain	Snow leopard habitat
Alpine forest (including conifer, scrubland)	Erosion control, water regulation, climate regulation, flood/landslide control, NTFP, MAPs, microclimatic control, habitat (biodiversity and wildlife conservation: wood snipe in scrubland), livelihoods (fuel, building materials, etc.), tourism, carbon sequestration
Rangelands: pasture, open grazing	Livelihoods (livestock and herding), tourism, NTFP, MAPs
Wetlands/lakes and ponds	Migratory bird habitat, tourism, storage, groundwater recharge, drinking water, water quality regulation, religious importance
Forest: mixed hardwood, broadleaf forest	Habitat (Red panda), NTFPs, MAPs, timber, firewood, fodder, livestock bedding, water recharge, erosion control, landslide and flood control, carbon sequestration
Freshwater (High Himalayas, High and Middle mountains): rivers, streams	High biodiversity in middle mountain region, water mills, ethnic community fisheries (livelihoods/subsistence in Middle Mountains), irrigation for commercial agriculture (Middle Mountains), hydropower, interbasin transfer in Middle Mountains, drinking water, sanitation, water quality, sand and gravel mining, recreation, cultural/religious, tourism (e.g., rafting)
Agroecosystem	Limited, 1-cycle, subsistence-based farming in the High Mountains; more varied 3- to 4-cycle commercial vegetable farming in the Middle Mountains

Table A-2. Impacts of economic development on water resources (quantity, quality, timing).

	Low growth 2.5% economic growth, with: • 3.6% in non-agricultural sector • 0.7% in agricultural sector	**High growth** 5.5% economic growth, with: • 6.6% in non-agricultural sector • 3.6% in agricultural sector
High Himalayas	**Quantity** – less impact, little consumptive use **Quality** – less impact **Timing** – less impact	**Quantity** – minimal direct human impact; but increased glacial and snow melt from black carbon **Quality** – minimal impact by tourism; some water pollution and solid waste pollution **Timing** – less impact, minimal increase in downstream flows
High Mountains	**Quantity** – very minimal impact **Quality** – very minimal impact **Timing** – very minimal impact	**Quantity** – some impacts, water consumption during dry season (tourism), increase population demand possible and new agriculture **Quality** – some impacts (tourism); could be even higher if large amounts of tourism, sanitation; infrastructure development (erosion from roads) **Timing** – some impacts (tourism)
Middle Mountains	**Quantity** – less impact compared to high economic growth **Quality** – less impact compared to high economic growth **Timing** – less impact compared to high economic growth	**Quantity** – high impact (low water flow, interbasin transfer), mostly during dry season; extensive water use for irrigation and loss of water (lowered water table) from sand and stone quarry; decrease in per capita availability, potential increase in industry demand (bottled water) **Quality** – high impact on quality from increased use of pesticides and fertilizers and sedimentation from sand and gravel mining **Timing** – high impact during dry season from increased consumptive use, causing changes to the hydrograph
Entire basin	**Quantity** – less impact **Quality** – less impact compared to high economic growth **Timing** – less impact compared to high economic growth	**Quantity** – high impact (irrigation, agriculture, hydropower, etc.) **Quality** – high impact (fertilizers, pesticides) **Timing** – high impact; long droughts, change in hydrograph from run of the river dams, low flows during the dry season from tourism and agriculture; more runoff and less recharge from sand mining leads to spikes in instream flows from precipitation events; simultaneously causing floods and lowering the local water table

Table A-3. Predicted climate changes and impacts across Nepal.

	Changes	Impacts (quantity, quality, timing)
Temperature	Significant rise in temperature Increase in the number of days & nights considered hot; highest temperature increases from June to August & at higher elevations; .7ºC per decade report from ICIMOD; other two reports state .4ºC and .29ºC; shift of snowline	Quantity – melting of glaciers, snow, higher evaporation, decrease in water storage capacity Timing – changes in the river flow (more in summer/wet season and long dry period; chances of GLOF and formation of glacial lakes; vegetation shift (positive)
Precipitation	Wide range of mean annual precipitation changes Increase in monsoon rainfall towards the end of the century; recent trend of decreased rainfall in monsoon; spatial variation	Timing – changes to seasonality of flows (wet and dry season)with long dry periods, uncertainties in precipitation, unpredictable water flows, changes in flow pattern;
Runoff	Higher downstream flows in short term, but lower in long term Shift from snow to rain in winter months at higher elevations More variability	**Quantity** – reduction of dry season flows through more prevalent and longer duration droughts; flash floods in wet season **Quality** – water quality deterioration from flows reductions and water chemistry changes (increased biota, etc.)
Extreme Events	Increased frequency and intensity of floods & droughts Increased frequency of GLOFs; crop failure; emergence of new pests and insects; drying out of spring sources; additional forest fires (due to decreased water)	**Quantity** – greater intensity and frequency of landslides, floods and droughts loss of life and properties, displacements, environmental degradation

Table A-4. Water resource impacts of combined development and climate change scenarios (quantity, quality, timing).

		Climate scenarios	
		Status quo	**High climate change**
Development Scenarios	Low Growth	With low climate impact and low economic growth, there is generally a lower impact on quantity, quality, and timing of water resources in the basin	High chance of getting impacts on quality, quantity and timing because of low coping and adaptive capacity
	High Growth	Commercial agriculture, drinking, irrigation, hydropower all will have significant impact on q, q, and t (increased consumptive use)	**Quantity** – decreased water availability due to increased consumptive use and long term decreased supply in the dry season; increased conflict due to localized water stress; permanent water stress due to decreased recharge and increased consumptive use; decrease in water storage capacity due to land conversion and increased droughts; drying out of springs due to high demand and droughts; lowering of groundwater table due to greater abstraction and less recharge
		Reduced flows due to increased consumptive use	
		Deforestation and increased runoff due to unplanned development of infrastructure (e.g., roads)	**Quality** – increased turbidity from higher sediment loading and decreased flows; decrease in quality due to increased pesticide use from increased prevalence of pests
			Timing – unreliable hydroelectric production due to inconsistent flows from increased demand and greater flows variability with the monsoon; increased landslides due to changes to land cover and the hydroperiod; lower dry season flows from agriculture, tourism, and drought; greater variability of flows in both wet and dry seasons due to both changes in climate (long periods of drought followed by intense rainfall events) and hydroperiod changes from land cover/ land use change (deforestation, terracing, roads) from development
			Other – decreased agricultural productivity due to increased pests and disease; increased poaching due to drying up of water holes and increased roads development; reduced carbon sequestration; native species replaced by exotics due to temperature shifts and development

Table A-5. Ecosystem vulnerability assessment.

		Climate-resilient ecosystem qualities				Average vulnerability
Ecoregion	**Ecosystems**	**Detrimental nonclimatic impact**	**Natural variability**	**Refugia**	**Connectivity**	
High Himalayas (above 5,000 m)	Cryosphere: glacier, snow, permafrost	Low – Negligible human impacts on the ecosystem	Medium	High – There are no/ limited areas buffered from substantial changes in climate	High – Connection from glacier to glacier is low, more barriers	Medium
	Scree/rugged mountain	Low – Negligible human impacts on the ecosystem	Medium	High – There are no/ limited areas buffered from substantial changes in climate	Medium	Medium
High Mountains (3,000–5,000 m)	Alpine forest (including conifer, scrubland)	Medium – Deforestation for timber not commercial use	High – Ecosystem is not accustomed to natural disturbance events	Medium	Medium	Medium
	Rangelands: pasture, open grazing	High – Over-grazing has a significant impact	Medium	Medium	High	High
	Wetlands/lakes and ponds	Medium – Tourism impacts are substantial, but only once/year	Medium	High – There are no/ limited areas buffered from substantial changes in climate	Medium	High
Middle Mountains (1,200–3,000 m)	Forest: mixed hardwood, broadleaf forest	High – There are many uses for forest products	Medium	Low – Microclimatic variation creates areas buffered from substantial changes in climate	Low	Medium
Trans-regional (cut across multiple ecoregions)	Freshwater (High Himalayas, High and Middle Mountains): rivers, streams	High – Industry, sand and gravel mining, agriculture	Low	Medium	Low	Medium
	Agroecosystem	High	High – System is not accustomed to natural disturbance events	High – There are no/ limited areas buffered from substantial changes in climate	High	High

Table indicates level of vulnerability, such that 'low' (yellow) means less vulnerability in terms of the criteria and high (red) means more vulnerability. If the ecosystem does not exhibit the characteristic, it is entered as null (left blank). So, for example, coloring the box for 'Detrimental non-climatic impact' yellow for 'High-altitude wetlands' indicates that human impacts like overgrazing and encroachment do not make this ecosystem component significantly more vulnerable

Table A-6. Final ranking of risk (based on ecosystem vulnerability and climate impact).

Ecoregion	Ecosystem	High growth/high climate change	
		Impact	*Risk*
High Himalayas (above 5,000 m)	Cryosphere: glacier, snow, permafrost	Rapid decrease in water storage	Medium
		Retreat in glaciers	High
		Reduced carbon sequestration	Low
	Scree/rugged mountain	Shift in scree	Low
		Shift in snow line	Medium
	Ecoregion as a whole	Waste and pollution	Medium
High Mountains (3,000–5,000 m)	Alpine forest (conifer and scrubland)	Native species replaced	Medium
		Forest encroachment/degradation/land use change	Medium
		Extreme events	High
	Rangelands (pastures, open grazing lands)	Increased degradation due to changes in livestock migration	High
		Reduced water storage	Medium
	Wetlands	Wetland degraded	High
		Drying of spring sources (High demand)	High
		Water pollution and waste	High
		Loss of biodiversity	High
		Extreme events	High
Middle Mountains (1,200–3,000 m)	Hardwood and mixed broadleaf forests	Forest degradation and fires	High
		Reduced carbon sequestration	Medium
		Increase in poaching	High
		Extreme events	High
	Region as a whole	Permanent water stress from decreased water availability and Reduced storage	High
		Loss of biodiversity (wetlands)	High
		Increase in pest/diseases	Medium
		Water quality degradation and pollution	Medium
		Landslide (unplanned roads)	Medium
		Drying of spring sources (High growth)	High
		Increased conflict from water stress	Medium
Trans-regional (cut across multiple ecoregions)	Freshwater (rivers and streams in High Himalayas, High and Middle Mountains)	Increased turbidity and deterioration of water quality	High
		Decrease in water availability	High
		Increased demand for water	High
		Conflict over water availability	High
	Agroecosystems	Decreased food security (High demand and decreased crop productivity)	High

High Risk: high vulnerability with medium/high impact; or medium vulnerability with high impact

Medium Risk: medium vulnerability with medium impact; high vulnerability with low impact; or low vulnerability with high impact

Low Risk: low vulnerability with low/medium impact, or medium vulnerability with low impact

Table A-7. Evaluation of existing policy.

Level	Policy/framework	Adequacy for adaptation	Barriers to implementation	Opportunities for improvement	Overall adaptive capacity
Local (VDCs, WUAs, etc.)	Regulations, guidelines, charter, constitutions, agreements	High	Medium	High	Low
	Water user groups agreements/ constitutions/operation plans	Medium	Medium	High	Low
	Community Forestry User Group (CFUG) forest operational plans	low	low	high	medium
	Local Self Governance Act (LSGA-2058)	Medium	Medium	High	Low
Regional (DDCs, Ministry Depts., etc.)	DDC development policies	Medium	Medium	Medium	Medium
National NAPA, Interim Plan, NGOs, etc.	Drinking water, sanitation, irrigation, forest, micro hydro	Medium	High	Medium	Medium
	Climate change policy	Medium	High	Medium	Medium
	NAPA	Medium	High	Medium	Medium
	National Water Plan (2005)	High	High	High	Medium
	Forestry Act/rules and regs	Medium	Medium	High	Medium
	Environmental Protection Act	Low	High	High	Low
International WB, NGO, plans, etc.	UNFCCC	Medium	High	High	Low
	Convention on Biodiversity	Medium	Medium	High	Medium
	International Labor Organization Convention 169 (indigenous people's rights)	Low	High	High	Low
	International Water Rights and regulations	Low	High	High	Low

Overall Adaptive Capacity is measured as a function of three factors Adequacy for Adaptation, Barriers to Implementation, and Opportunities for Improvement. Adequacy for Adaptation measures the inherent adaptability of the policy and its relevance for responding to the impacts of climate change. Barriers to Implementation measures the degree to which identified factors prevent implementation of policies, and Opportunities for Improvement measures the extent to which the analyzed policy in its current state can be improved upon.

- Low capacity (high vulnerability) [red]
- Medium [orange]
- High capacity (low vulnerability) [yellow]

Table A-8. Evaluation of existing infrastructure.

Level	Level/type	Operations & maintenance	Policy/framework	Adequacy for adaptation	Barriers to implementation (proposed only)	Opportunities for improvement	Overall adaptive capacity
Local	Roads/bridges	Periodic/annual; not well maintained	Guided by national ministries	Low	Medium	High	Medium
	Farmer Managed Irrigation Systems (FMIs)	Periodic; well managed	Community-based agreements	Medium	Low	Medium	Medium
	Drinking water supply	Minimal; "O&M effectiveness depends on ownership (donor, government – not well maintained; farmer managed – well maintained)"		Low	Medium	Medium	Low
	Micro-hydro	Well managed	NEA rules and regulations	Medium	High	High	Medium
Regional	Roads/bridges	Annual/periodic; poorly maintained	Policy in place, but weak implementation	Low	Medium	High	Medium
	Water and sanitation	Less effective	Good policy, but weak implementation	Low	Low	High	Low
	Industrial (dairy)	Well managed but needs improvement		Low	Low	Low	Low
	Hydropower	Regular	NEA rules and regulations	Medium	High	High	Medium
National	National hydropower (Indrawati III)	Poorly maintained	Policy in place, but weak enforcement	High	Medium	High	Medium
	Melamchi interbasin transfer	Poorly managed	Policy in place, but it faces political hurdles	High	High	High	Medium
	Industrial	Regular	Respective line ministries	Medium	Medium	High	Medium
	National electricity grid	Regular	NEA rules and regulations/ Electricity act 2020	Medium	Medium	High	Medium
	Roads network	Annual/periodic	Dept. of Roads/ MOLD	Medium	Medium	Medium	Medium
	Drinking water	Regular	"Physical planning"	Low	High	High	Low

Overall Adaptive Capacity was measured as a function of three factors Adequacy for Adaptation, Barriers to Implementation, and Opportunities for Improvement. Adequacy for Adaptation is measured by the extent to which the infrastructure helps cope with climate variability. Barriers to Implementation measures the extent to which there are hurdles to developing new/planned infrastructure, and Opportunities for Improvement measures the extent to which infrastructure in the basin can be improved to reduce vulnerability in the basin.

Low (high vulnerability)

Medium

High (low vulnerability)

Table A-9. Comprehensive list of adaptation options from the national level workshop in Kathmandu.

Ecosystem	Impact	Risk	Adaptation Options "Best" solution combinations of "hard," "soft," and "natural" infrastructure
Cryosphere: glacier, snow, permafrost	Rapid decrease in water storage	Medium	Baseline data collection; disaster prevention; early warning systems
	Retreat in glaciers	High	
	Reduced carbon sequestration	Low	
	Shift in snow line	Medium	
	Waste and pollution	Medium	Clear tourism related waste disposal policies; payment for ecosystem services
Scree/rugged mountain	Shift in scree	Low	
	Shift in snow line	Medium	
	Waste and pollution	Medium	Clear tourism related waste disposal policies; payment for ecosystem services
Alpine forest (including conifer, scrubland)	Native species replaced	Medium	
	Forest encroachment/degradation/land use change	Low	
	Extreme events	High	
Rangelands: pasture, open grazing	Increased degradation due to changes in livestock migration	High	Land use zoning, policy enforcement
	Reduced water storage	Medium	
	Extreme events	High	
Wetlands/lakes and ponds	Wetland degraded	High	Identification of critical wetlands and put in place RAMSAR and site management plan and afforestation
	Drying of spring sources (high demand)	High	
	Water pollution and waste	High	
	Loss of biodiversity (wetlands)	High	Policy enforcement and capacity of local institutions
	Extreme events	High	
Forest: mixed hardwood, broadleaf forest	Reduced carbon sequestration	Medium	Enforcement of conservation laws; forest conservation; emission reduction and clean energy
	Forest degradation and fires	High	Enforcement; protected areas and buffer zones around forests; fencing forest management and fire line construction
	Increase in poaching	High	Protected areas, web and digital (camera) to protect species
	Extreme events	High	Soil and water conservation act and regulations; awareness and advocacy programs; forest and land use management; embankments and bioengineering
	Increase in pest/diseases	Medium	Pesticides act and agriculture policies awareness; integrated pest mgmt. (IPM) and biopesticides
	Landslide (unplanned roads)	Medium	Forest and land use mgmt.; embankments and bioengineering

Ecosystem	Impact	Risk	Adaptation Options "Best" solution combinations of "hard," "soft," and "natural" infrastructure
Rivers/water bodies	permanent water stress from decreased water availability and reduced storage	High	Water, forest, wetland conservation and restoration; afforestation; rainwater harvesting; spring source conservation; water storage structures (reservoirs and tanks)
	water quality and pollution	Medium	Water quality standards; treatment plants; spring source protection
	unreliable hydropower	High	Alternative energy source; forest protection and source protection; increased storage capacity
	drying of spring sources (High growth)	High	Forest, water, springs conservation and awareness, source protection
	increase in pest/diseases	Medium	Pesticides act and agriculture policies awareness; IMP and biopesticides
	landslide (unplanned roads)	Medium	Forest and land use mgmt.; Embankments and bioengineering
	increased conflict from water stress	Medium	Equal distribution mechanism; prioritization of use; source and forest protection; drinking water and irrigation infrastructure
Agroecosystem	increase in pest/diseases	High	
Freshwater (High Himalayas, High and Middle Mountains): rivers, streams	increased turbidity and deterioration of water quality	High	Capacity building for local level oversight of sand and gravel mining industry; better implementation of regulations soil bioengineering; and river training
	decrease in water availability	High	Best agricultural practices; soil and agriculture tech; water and soil conservation; groundwater recharge; regulations for environmental flows; irrigation infrastructure improvement; strengthened local groups and incentives programs
	increased demand for water	High	
	conflict over water availability	High	
Agroecosystem	decreased food security (high demand and decreased crop productivity)	High	Policy reforms to restore subsidies for farmers (for fertilizer); organic farming and efficient technology

High Risk: high vulnerability with medium/high impact; or medium vulnerability with high impact

Medium Risk: medium vulnerability with medium impact; high vulnerability with low impact; or low vulnerability with high impact

Low Risk: low vulnerability with low/medium impact, or medium vulnerability with low impact

APPENDIX B: FIELD WORKSHOP IN CHAUTARA, DAY ONE

Table B-1. Key ecosystems and why they are important.

Ecoregion	Ecosystem	Why is it important? (e.g., to livelihoods, ecosystem services, cultural/religious values)
High Himalayas (above 5,000 m)	Glacier, snow, rocky mountain	Water, source of river, tourism, aesthetic beauty, minerals, snow, glacier
High Mountains (3,000–5,000 m)	High Mountain forest	Soil conservation, NTFPs, MAPs, Red panda, wildlife habitat
	Rangelands: pasture, open grazing	Livestock farming, yak, sustainable livelihood, erosion control, infiltration, animal husbandry, income generation
	Agriculture system	Potato, hulless barley (used for tea, butter, and local wine), subsistence and commercial farming
	Wetlands/lakes and ponds	Religious aspect, tourism, headwater, water source
Middle Mountains (1,200–3,000 m)	Forest: mixed broadleaf forest	Water recharge, soil conservation, fuelwood, fodder, source of water, NTFPs, MAPs, timber, litter, compost, barren land 3%–5%, broad Leaf for 30%–35%
	Agriculture system	Sustainable livelihood, cropping intensity, commercial farming, cardamom, cash crops
	Pine forest	No/less water recharge, no/less shrubs, resin tapping, timber, aesthetic value, greenery formation.
Trans-regional (cut across multiple ecoregions)	Freshwater (High Himalayas, High and Middle Mountains): rivers, streams	Hydropower, Melamchi Transfer, irrigation, tourism, mining (sand and gravel), recreation, fisheries, drinking water.
	Agricultural Ecosystem	Sustainable livelihood, subsistence and commercial farming, habitat for pest (agro-ecology)

Table B-2. Trends in climate and development for key ecosystems.

			Cause		Rank (complete after Table B-3)
Ecoregion	**Ecosystem**	**What changes or trends have been observed in these ecosystems?**	**Climate**	**Development**	
High Himalayas (above 5,000 m)	Snow, Glacier lake, Rocky mountain	Accelerated snow melt and retreating snow lines compared to previous decades			6
High Mountains (3,000 to 5,000 m)	High-altitude forest,	Selang, Bhotang, Golchey, Thaupalkot (degradation, deforestation)			7
	Rangeland (Selang ground), Agricultural System, wetlands, streams/rivers	Forest fire have increased (361 places at once)			5
		The flowering time of Rhododendrons have changed (it is now seen during the month of Jan to Feb which earlier used to be seen only during the month of March and April. (Sinpalgabre)			
		Conversion of forest to shrub land			
		The source of water has dried out (seasonality shifts). Seasonality shfits: too much water in the wet season (July–Sept) and too little water in the dry season (Jan–Feb) – Shikharpur			1
		Changes in the flow of water pattern in the river (almost decrease by half in 20 to 25 years)			
		Landslide, flood, soil erosion			2
		Increase in harmful pests (mostly in summer season)			7
		Agriculture productivity decrease in rain-fed area (Alae–Malae weeds increased, grasshopper increased, frog decreased, scorpion decreased, spider decreased, snake decreased			3
Middle Mountains (1,200 to 3,000 m)	Forest: mixed forest	Forest fire			5
		Invasive species (cat weed/banmara, aalu-jhar (it bears yellow flower), the pine species have shifted upwards			7
		Loss of species (kadam)			6
		Simal tree species have decreased in number			6
	Pine forest	Forest fire have increased, preventing sapling growth			
		Drying of land from changes in rainfall patterns (total rainy days have decreased, but total annual rainfall is the same due to shorter, but more intense rainfall events that cause flooding and reduce groundwater recharge)			1
		The pine forest to be converted into mixed broadleaf forest within 20 years			
	Agricultural System	More use of pesticides			
		Khumle insects amount have increased (local pests)			
		Disappearance of leech and other insects due to high use of pesticides.			6
		Changes in rice cropping patterns (shifts in seasons due to changes in the monsoon)			
	Rangeland	Decrease in the productivity of grasses (Nawal pur)			
Trans-regional (cut across multiple ecoregions)	Freshwater (High Himalaya, High and Middle Mountains): rivers, streams	Decrease in the quantity of freshwater			
		Streams are dry during the dry season and the flow is heavy during the wet season			
		The threat for the fisherman in the area			9
		Drought (drying up and loss of water sources)			10
		Landslides, siltation, reductions in streamflows downstream due to upstream development			
		Lowering of the natural flow in the river			
		Upland – landslide			2
		Lowland – bank cutting, flood (e.g., Bade Gaun 3-4 times last year, 300 ropani of rice farm damaged); in Bade Gaun 4, one whole community was displaced due to landslide and flood			4

Table B-3. Determining vulnerability.

Ecoregion	Ecosystem	Vulnerability criteria		
		How high is the anthropogenic impact?	Does the ecosystem often experience and survive floods, droughts, fires, or landslides?	How dependent are people on the ecosystem?
High Himalayas (above 5,000 m)	Glaciers, snow, rocky mountain	Low – less human settlement	Low (high vulnerability)	Low – low human settlement
High Mountains (3,000 to 5,000 m)	High-altitude forest	Low – less human settlement	Medium – forest fire	Medium – wood, grazing
	Rangeland	Medium – more grazing	Medium – landslide	High – livestock, occupation, grazing
	Wetlands	Medium – some grazing	Low – less relevant	Low – tourism, kutki
	Agriculture system	High – agriculture	Low – less intervention	High – food security
Middle Mountains (1,200 to 3,000 m)	Mixed broadleaf forest	High – forest fire, more population, roads, fuel, fodder	High (low vulnerability) – increased forest fire, subtle landslide	High – sustainable livelihood
	Agriculture system	High – pesticide, fertilizer, development of intensive agriculture	High (low vulnerability) – landslide, flood, drought are common	High – sustainable livelihood
	Pine forest	High – effective changes, forest fire, limited use	High – forest fire, erosion, other events are moderate	Medium – limited use
	Rangeland	High – overgrazing	High – soil erosion, moderate forest fire	High – sustainable livelihood, livestock
Trans-regional (cut across multiple ecoregions)	Freshwater, stream	High – intensive farming development, water scarcity, pollution, sewage, sand and mining, important aquatic species	High – flood, drought, landslide relatively common	High – irrigation, drinking water, hydropower, mining, some fish
	Agriculture ecosystem	High – income, sustainable livelihood, occupation, fertilizer, pesticides	High – soil erosion, river bank cutting, drought, flood are common	High – sustainable livelihood

Table B-4. Adaptation options.

	Impacts	Given these ranked impactsfrom Table B-2 and vulnerabilities from Table B-3, what are the best options for adaptation?	How do people usually respond to the climate impacts form Table B-2?
1	Drying of the water source	Plantation, awareness, catchment ponds, artificial recharge ponds, landslide treatment, conservation of forest, afforestation	
2	Landslide	Control of landslides, enforcement of existing policies and regulations (forestry and watersheds), maintenance of river and stream	
3	Infrastructure damages from unplanned roads and landslides	Gabion wall, afforestation, awareness raising	
4	Flood/river bank cutting	River training, enforcement of existing policies and regulations (forestry, watersheds)	
5	Forest fire	Early warning system, fire line, training, extension activity	
6	Loss of species (animals and plants)	Forest management tools	
7	Forest degradation	Conservation, afforestation	
8	Drying out of the rivers	Conservation of the water source, upstream–downstream linkage/coordination, payments for ecosystem services (PES)	
9	Threats to fishermen	Inventory, fishery training, alternative livelihood, conservation of aquatic habitat	
10	Drought	Catchment pond, rain water harvesting, roof water harvesting, natural forest/catchment conservation	

APPENDIX C: FIELD WORKSHOP IN CHAUTARA, DAY TWO

Table C-1. Key ecosystems and why they are important.

Ecoregion	Ecosystem	Why is it important? (e.g., to livelihoods, ecosystem services, cultural/religious values)
High Himalaya (above 5,000 m)	Dudh Pokhari, Glacier Lake, Snow, chyakshal pond, Black rock	Aesthetic beauty, source of water (freshwater), herbs (Yarshagumba), animal habitat (Musk deer)
High Mountains (3,000 to 5,000 m)	High-altitude forest	Gobre Pine, Devdar, Rhododendron, Quercus (oak species), source of water, tourism, recreation, NTFPs (herbs, teemor (Xantho Xylum Armatum), fooder), habitat for birds, grazing animals (primarily yak)
	Rangeland, grassland, alpine meadow	For grazing (yak), soil conservation, fodder, medicinal herbs (nirvese, jatiemasi, panchaullee, chiraieto, banmulla, Yarshagumba)
	Agriculture ecosystem	Primarily potato, barley, millet crops; food security, sustainable livelihood, exchange of goods, trading of goods
	Wetland, lake	Panch pokhari - religious (Janai purnima and ekadashi have rush), tourism (national and international), source of indrawati, habitat for birds and animals.
Middle Mountains (500 to 3,000 m)	Coniferous forest, pine (khote sallo), gobre sallo, Rhododendron, dhupi,	Conserving source of water, control of soil erosion, forest species; NTFPs, MAPs. Source of energy, animals and bird habitat, tourism (Nawalpur- rhododendron)
	Chilawne jhar, Lapsi, Hazelnut, Simal, bamboo, nigalo, uttis	Groundwater recharge (broadleaf forests have high recharge capacity at 30-35%), soil erosion control, NTFPs and MAPs; biomass energy source; bird, animal habitat; timber
	Agricultural ecosystem – potato, millet, beans, maize, rice, wheat, vegetable farming	Food security, sustainable livelihood, economically beneficial, cash crops (commercial farming much more commonplace, is the main income source in the region), eco friendly environment for the other organism (bee, earthworm, spider,), control of soil erosion
	Rivulet, lake	Irrigation, source of water, biodiversity/habitat, drinking water
Trans-regional (cut across multiple ecoregions)	Indrawati, Melamchi, Hadie Khola, Tiepeni Khola	Irrigation, energy, drinking water source, storage, aquatic habitat, tourism (though not in stream like rafting; river is too flat), Pani Ghatta, income source, sand and gravel mining

Table C-2. Trends in climate and development for key ecosystems.

			Cause		Rank (Complete after Table C-3)
Ecoregion	**Ecosystems**	**What changes or trends have been observed in these ecosystems?**	**Climate**	**Development**	
High Himalayas (above 5,000 m)	Snow, glacier lake, rocky mountains	Rapid snowmelt, drying out of glacial lakes; decreased snowpack compared to previous years; receding snow line; water quantity reductions from increasing tourism pressure on drinking water supplies			1
High Mountains (3,000–5,000 m)	High-altitude' forest,	Forest degradation, (soil erosion, road development, atmosphere pollution); land conversion to shrub			3
		Landslides			9
	Rangelands	Biodiversity loss (drought; loss of medicinal herbs; invasive species [Jagatmara])			6
	Wetlands/lakes and ponds	Less water, lower water tables seen in wetlands			
	Agriculture ecosystem	Cropping pattern changes (new plantation, the fruiting of Kafal is out sometimes early and sometimes it does not come out at all, earlier flowering of rhododendron in the month of march)			4
		Increased plant disease			7
Middle Mountains (1,200–3,000 m)	Coniferous Forest	Seasonal vegetation shift (falling of litters used for compost and fertilizer has shifted from the month of March–April to the month of May–June, berberis, ainselu, and guava are not found much anymore)			
		Forest degradation, (Soil erosion, road development, atmosphere pollution)			3
		Landslides			9
	Rivers and Streams	Drying out of water sources		Forest degradation, crusher industry, road development	1
		Water pollution		Fisheries impacts from pesticides	8
		Loss of fish species in upper region and extinction in the lower region			6
	Agriculture Ecosystem	Lowering of the river level, irrigation sources (approx. 500 Ropani was irrigated before, but now only approx. 100 Ropani area is irrigated)		Sand and gravel mining	
Trans-regional (cut across multiple ecoregions)	Agriculture ecosystem	Increased use of pesticides, fertilizers	temperature increases, use of chemical fertilizer		4
		Increased prevalence of plant diseases			7
		Decrease in the production, low irrigation facility	Irregular rainfall	Minimal irrigation infrastructure, much of which is in disrepair	2
		Changes in cropping patterns (from rice to millet and wheat, difficulty in timing transplantation)			5
		The indigenous seeds of papaya and guava are destroyed		Hybrid seed	
	Rivers and rivulet	Ground water use increased, less runoff/less storage, river pollution, lowering of the river level, loss of aquatic species		Urbanization, sand and gravel mining, chemical fertilizer	
		River bank erosion and floods			10

Table C-3. Vulnerability assessment.

		Vulnerability criteria		
Ecoregion	**Ecosystems**	**How extensive is the anthropogenic impact?**	**Does the ecosystem often experience and survive floods, droughts, fires, or landslides?**	**How dependent are people on the ecosystem?**
High Himalayas (above 5,000 m)	Snow, glacier lake, rock	Low – important for religious and mountain tourism, but less direct human impact from only minimal human settlements	High vulnerability – such events rarely occur, have a negligible impact	Medium – depend on water in an indirect way
High Mountains (3,000–5,000 m)	High-altitude forest	Medium – grazing, maps	High vulnerability – drought, forest fire have mild impact	Medium – grazing, maps and farming to sustain lives of the local people
	Rangeland, agriculture	Medium – there is some grazing, but in general not as much cultivable, fertile land	High vulnerability – landslide, forest fire very occasional	Medium – land dependence is more small scale, sustainable, with some livestock, but there has also been significant labor migration outside the basin
	Wetlands	Medium – Drying out; degradation	Medium – ecosystem is somewhat accustomed to droughts, floods	Medium – water, medicinal herbs
Middle Mountains (1,200–3,000 m)	Coniferous forest	High – timber, trade of NTFPs, fuelwood, fodder, road construction all cause/ contribute to forest degradation	Low vulnerability – forest fires, drought,; mild landslides, are more common	High – timber, fodder and fuelwood
	Agriculture	High – with a 4-crop cycle rotation, there is a heavy impact from agriculture	Low vulnerability – ecosystem is accustomed to wide variability of rainfall, including periods of drought	High – high percentage of local populations depend on ag. for livelihoods; food security is critically dependent
	Stream, lake	High – chemical fertilizers and pesticides, electrical current used to kill fish	Medium – ecosystem is somewhat accustomed to droughts, floods, landslides, and wide variation in rainfall patterns	High – irrigation
Trans-regional (cut across multiple ecoregions)	River	High – there is significant impact throughout the basin from road construction (siltation and landslides) and the sand and gravel mining industry	Medium – sustaining	High – throughout the basin, people are highly dependent on freshwater for irrigation, fisheries, and drinking water

Table C-4. Assessment of existing policies.

Level	What are the most important formal and informal natural resource management policies, frameworks, customs, or agreements?	How can they be improved?
Local	1. Water related: Water Act, Irrigation policy, registration of water source (Muhan Darta)	Change in water source registration practices (many users register now to reap benefits without investing in drinking water, hydro, irrigation, etc.)
		Community participation/awareness
	Informal institution	Better enforcement and regulation of existing water policies and regulations
	1. Forest-related: community forest, religious forest, leasehold forest, private forest.	Water distribution should be clarified
	2. Agriculture: cooperative practices, land reform practices, commercial practices	Basic Rights need to be protected
		Education for local users on existing policies and regulations (water use rights and limitations, relevant approval/oversight agencies, and fines and punishments for violations)
	Community policies are made by the community itself; monitoring, penalties for offense, water allocation (turn wise)	Better implementation and more effective monitoring
	Dhad Khola – forest community	
	Somewhere first-come, first-served (Shikharpur)	Crop insurance, livestock insurance
		Local community agriculture groups to discuss water efficiency technologies, best practices, and innovative tools like integrated pest management (IPM)
		Support price/minimum price/land reform
		Promoting organic farming
Regional	1. Forest – District Office Approval	Capacity building for existing staff around new agriculture and water management best practices and new technologies; improvements in monitoring and enforcement; better access to ag. markets; enlisting new staff
	2. Agriculture – District Office Approval	
	3. Cooperative – Division Office	

Table C-5. Determining existing institutional capacity.

		Capacity (high, medium, or low)		
Level	**Institution Type (DDC, VDC, user groups, Ministry Dept. Field Offices, etc.)**	**Financial resources**	**Decision-making power**	**Human resources**
Local	Community Forestry User Groups (CFUGs)	Low (high vulnerability) – could increase if harvest permits were collected	Low (high vulnerability)	Medium
	Agriculture – Cooperative, Collection Centre	Medium	Medium	Medium
	Drinking Water User Committee	Low	Medium	Medium
	Irrigation User Committee	Low	Medium	Medium
Regional	Water – Divisional Office (Irrigation) at Dhulikhel, Sindhupalchowk, Kavre	High (low vulnerability)	Medium	Medium (e.g., irrigation corridor program)
	Regional Forestry Directorate	Medium	Medium	Low
	Regional Agricultural Directorate	Low	Medium	Low (only one Junior Technical Assoc. for 6 VDCs)
	DDC	High	Medium	Medium

Table C-6. Adaptation options.

	Impacts (from Table C-2)	Given these ranked impacts, relevant policies from Table C-4, and adaptive capacity from Table C-5, what are the best options for adaptation?	How do people usually respond to the climate impacts from Table C-2?
1	Drying of the source of water	Source conservation, maintenance of damp area	Effective water use, plantation around the source and conserve tree, temple construction
		(capacity building, training, afforestation, nursery)	
2	Loss in the soil fertility/decrease in production	Soil test, promote organic farming, technical capacity building and subsidy in agriculture	More and more use of chemical fertilizers
3	Forest degradation/forest fire, road construction, public construction	Plantation, nursery, conservation, planned road construction, awareness on forest fire, more training for local populations	Has been used in cooperation with community forest
4	Land pollution (chemical fertilizer)	Organic farming technique, organic fertilizer, awareness, enforcement and monitoring of existing laws and regulations	Effective use
5	Changes in the crop pattern/not being able to cultivate in time	Studies on climate change impacts on crop yields and necessary responses (ie different seed varieties, land preparations, fertilizer, pesticides, watering, etc.), irrigation facility, alternative crops (agriculture system) IPM, rainwater harvesting, conservation pond	To only limited extent
6	Loss of species (plant/animals)	Less use of pesticide, source conservation, less mining	
7	Diseases in plants	Organic fertilizer	High use
8	Water pollution (waste products)	Awareness, implementation of existing water pollution laws and regulations	Possible effort on the community forest
9	Landslide – forest fire	Landslide – afforestation, river embankment, gabion wall	Soil conservation/water induced disaster management office has been working on such issues
		Forest fire – awareness punishments/fines for starting fires, training and tools	
10	River bank cutting/flood	River embankment and retention program, afforestation	
		effective development, soil conservation	
		water induced disaster management	
		sustainable development	
		community involvement	

the Nicholas Institute

The Nicholas Institute for Environmental Policy Solutions at Duke University is a nonpartisan institute founded in 2005 to help decision makers in government, the private sector, and the nonprofit community address critical environmental challenges. The Institute responds to the demand for high-quality and timely data and acts as an "honest broker" in policy debates by convening and fostering open, ongoing dialogue between stakeholders on all sides of the issues and providing policy-relevant analysis based on academic research. The Institute's leadership and staff leverage the broad expertise of Duke University as well as public and private partners worldwide. Since its inception, the Institute has earned a distinguished reputation for its innovative approach to developing multilateral, nonpartisan, and economically viable solutions to pressing environmental challenges.

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