Adaptation to Water Scarcity in Glacier-Dependent Towns of the Indian Himalayas: Impacts, Adaptive Responses, Barriers, and Solutions

By

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Abstract

Among the existing and projected impacts of climate change, impacts on water resources are expected to exacerbate the current and future threat of global water scarcity. Glacier-dependent societies are especially vulnerable to water scarcity due to the more pronounced effects of climate change on glacial systems that govern the water availability of these societies. In this thesis, water scarcity is examined as an impact of climate change in Dharamshala and Leh, two glacier-dependent towns of northern India, while recognizing that climate change is not the only factor causing depletion of water resources in these towns. In order to show the linkage between climate change and water scarcity, evidence is presented on changes occurring in the towns' local climate parameters such as snowfall, rainfall and temperature, as well as changes in the hydrology of the water bodies that make water available to these towns. This establishes that water scarcity in these towns has been induced not only by increasing demand, but also by decreasing supply of water.

In light of the water scarcity facing these towns, an investigation of the measures taken by their local governments to address this issue is presented, which reveals that the primary adaptive response employed in both towns has been supply augmentation. The driver behind this response has been the pursuit of economic development to improve the standard of living of Dharamshala and Leh's constituents. It is argued that economic development as a driver has not been effective in inducing holistic adaptive responses to water scarcity. Additionally, climate change considerations have been largely absent in the policy/planning processes that govern water management in both towns, implying that the responses of Dharamshala and Leh to water scarcity have been influenced by the pursuit of short-term economic benefits in a local economy that fails to recognize the importance of the integrity of water resources to its sustenance. The perpetuation of unsustainable economic development and failure to account for climate change impacts in local water management points to the presence of several technological, structural, financial, and political barriers to the planning/implementation of holistic climate-centric strategies for adaptation to water scarcity in Dharamshala and Leh. Therefore, in the concluding part of this thesis, recommendations are offered to enable the local governments of Dharamshala and Leh to overcome these barriers.

Keywords: climate change, impacts, adaptation, city adaptation, glaciers, snow-pack, glacier-dependent cities, barriers, solutions

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Acronyms and Abbreviations

CBA	Community Based Adaptation
CRA	Community-based Risk Assessment
DIHAR	Defense Institute for High Altitude Research
DRDO	Defense Research and Development Organization
GLOF	Glacial Lake Outburst Flood
IBT	Increasing Bulk Tariffs
ICIMOD	International Centre for Integrated Mountain Development
IEC	Information, Education & Communication
IPCC	Intergovernmental Panel on Climate Change
IPH	Irrigation and Public Health
IWRM	Integrated Water Resources Management
J&K	Jammu & Kashmir
KL	Kilo-Liter
LAHDC	Leh Autonomous Hill Development Council
LEDeG	Ladakh Ecological Development Group
LEHO	Ladakh Environmental Health Organization
LNP	Leh Nutrition Project
LPCD	Liters Per Capita Per Day
LPD	Liters Per Day
MC	Municipal Council
MLD	Million Liters per Day
MOeF	Ministry of Environment and Forests
NAPCC	National Action Plan on Climate Change
NGO	Non Governmental Organization
PHE	Public Health Engineering
PSP	Public Stand-Post
R&B	Roads & Buildings
RCM	Regional Climate Model
Rs.	Rupees
UNEP	United Nations Environment Programme

Chapter 1: Introduction

Climate change is expected to affect cities and towns throughout the world. Most scientific experts agree that accumulated historical emissions of greenhouse gases have already committed the earth to a significant level of warming and the impacts of this warming are already being felt. Among the adverse impacts of climate change, water scarcity is an immediate as well as long-term threat to millions living in urban settlements.

A closer look at the regions of the world which will be impacted by climate-induced water scarcity reveals that areas depending on snow-melt are particularly vulnerable. These regions have been identified as "especially affected areas" by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2007). Global climate change models used by IPCC have made predictions that mountain glaciers and snow-cover have declined in both hemispheres on average, and that the maximum areal extent of seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with decreases in spring of up to 15% (IPCC 2007). Some hydrological systems are beginning to experience increased runoff and earlier peak discharge in rivers due to the melting of larger permanent glaciers from higher winter and spring temperatures. This melting of permanent glaciers can continue throughout the summer, yielding greater discharge. On the other hand, some water bodies which depend on the annual cycle of snow-pack accumulation and melting of smaller non-permanent glaciers are experiencing a reduction in discharge of melt-water in the summer as a result of reduced snow cover and/or early melting from higher winter and spring temperatures (IPCC 2007).

In the case of the Himalayan glacial system, considerable uncertainty still persists about the behavioral response of Himalayan snow-pack and glaciers to climate change. Climate models developed by IPCC are continuously modified based on new scientific information, with the most recent model projections being significantly different from those that were made in past reports for the state of the Himalayan glacial system. In fact, IPCC has come under severe criticism for erroneous estimates about the rate of recession of Himalayan glaciers. One of the observations in the IPCC's Fourth Assessment Report[1], which stated that all Himalayan glaciers are likely to disappear by the year 2035, has been proven to have no scientific basis. A study released by the Ministry of Environment and Forests (MoEF) of the Government of India in November 2009 states that even though Himalayan glaciers are shrinking in volume and constantly showing a retreating front, they are not retreating at an abnormal rate, particularly in the last decade (Raina 2009). This new finding illustrates the disparities seen in regional climate models and evidence of climate change impacts at the local level. In light of this evidence, this thesis operates under the following premises: climate models currently do not have the resolution required to accurately project impacts at local levels. This is a significant limitation in current research on climate science, given the complex, heterogeneous nature of the Himalayan glacial system. Additionally, even though there continues to be a debate over whether the current rate of retreat of most Himalayan glaciers can be attributed to climate change caused by anthropogenic activity, evidence at the ground level leaves little doubt that changes are taking place in the glacial hydrology of the Himalayas in ways that are affecting the urban ecosystems embedded within the Himalayas. In other words, there is no debate that the glacial hydrology of the Himalayas is changing. The debate lies in opinions about the underlying cause of this changing glacial hydrology: natural climate change,

[1] The IPCC's Assessment Reports present scientific, technical and socio-economic information relevant for the understanding of human-induced climate change, potential impacts of climate change and options for mitigation and adaptation. The latest Assessment Report was released in 2007.

anthropogenic climate change, or simply over-extraction of natural resources as a result of population growth and development (which suggests that water scarcity is a result of increasing demand, and not decreasing supply).

Experts are in disagreement over whether water scarcity in the north Indian region has manifested as a result of economic development, or climate change, or both. In general, there is consensus among experts that climate change is not the only factor responsible for water scarcity expected to impact regions of the world, but rather climate change is expected to exacerbate water shortage resulting from factors such as population growth, particularly in the developing world (Vorosmarty, et al. 2000). For example, in the water shortage hotspots that have been identified across the world, the total number of people who will be impacted by water scarcity is estimated to reach 5 billion by 2025, but climate change will account for roughly 20% of this growth in scarcity, implying that most of the impacts on water resources are due to other factors like population growth or socio-economic development (Ehrhart 2008). But what is important to note is that climate change will result in changes in the timing, intensity, duration, and form of precipitation (i.e. snow versus rain), all of which are equally important determinants of water scarcity in addition to the quantity of precipitation (Rogers 2010). Thus, even if efforts are initiated to mitigate water scarcity expected to result from economic development, if these efforts are made without climate change considerations, they will not be as effective.

In light of these factors, this thesis explores water scarcity in the context of climate change in two small towns of northern India that rely on Himalayan glaciers for their water supply, while recognizing that water scarcity can manifest as a result of other factors like socio-economic development. Specifically, this analysis studies the ways in which water scarcity has emerged in these towns, along with the kinds of responses to water scarcity taking place in these towns. Additionally, it explores how adaptation planning and implementation differs in these towns, and identifies the drivers of their responses to water scarcity. Based on the analysis of drivers, this thesis determines the extent to which climate change implications are considered in the policy/planning processes governing responses to water scarcity in the towns. In other words, it is determined if the responses of the towns to water scarcity could be categorized as adaptation to climate change per se, or simply as a form of natural resource management. Lastly, this thesis identifies existing barriers to the formulation of a comprehensive adaptation framework for addressing water scarcity in these towns, particularly a framework that acknowledges both climate change as well as natural resource depletion resulting from economic development. In light of these barriers, recommendations are provided for the ways in which the towns could better adapt to water scarcity beyond what they are currently doing to cope with this impact.

Keeping in mind that this thesis is situated in the framework of adaptation to climate change, Chapter 2 presents a literature review of various themes that fall within the realm of climate change adaptation, such as general impacts, the consequent need for adaptation, the desirable characteristics of adaptation, the current status of adaptation, barriers to effective adaptation, and typical drivers of adaptation in local governments. Additionally, background is provided on the roles of various stakeholders in adaptation, along with an overview of the different scales at which adaptation can take place. Lastly, Chapter 2 briefly introduces the concept of extreme cases, which are relevant to this thesis as it focuses on a specific kind of climate change impact (water scarcity) in a specific type of location (glacier-dependent towns).

Given the specificity of this thesis topic, Chapter 3 reviews impacts of climate change in mountain systems and glacier-dependent cities. In particular, effects of climate change on glacial melting processes and downstream hydrology are explicated, along with the implications of these impacts for urban systems that derive their water supply from glacial systems. Chapter 4 presents the methodology and research design employed for conducting field-work in the two towns of northern India that were identified as the case-studies for this thesis: Dharamshala and Leh. Chapters 5 and 6 contain a detailed description of Dharamshala and Leh respectively, including a background on their location, climate, political history, socio-economics, the evolution of their water management system, sources of water supply, current and projected water demand and supply, impacts of climate change, and evidence of adaptive responses to water scarcity from various sectors in these towns.

Chapter 7 presents an analysis of the observations made in the two case-studies. Specifically, this chapter explicates the similarities and differences found in the planning and implementation of the two towns with regard to water management. Based on these comparisons and contrasts, this chapter analyses the primary drivers of planning and implementation measures that have taken place in Dharamshala and Leh in response to water scarcity, and identifies whether these measures take into consideration the additional impacts of climate change on water resources. Simultaneously, barriers to a more climate-centric, progressive, holistic, and anticipatory form of adaptation are identified in this chapter on the basis of observations made about the current management of water resources in both towns.

Finally, Chapter 8 presents recommendations that may enable the local governments of Dharamshala and Leh to address water scarcity by employing more climate-centric, progressive, holistic, and anticipatory forms of adaptive planning in their water management. A lot of these recommendations are framed such that they are within the scope of what local governments can do to improve their adaptive capacity to water scarcity in the absence of external assistance.

The findings of this analysis show that the main strategy that the towns of Dharamshala and Leh have employed in addressing water scarcity thus far has been water-supply augmentation. The primary motivations behind this choice of strategy have been goals of economic development and improved standards of living in both towns. Moreover, under the current structure of the economies of both towns, it appears that measures for any form of environmental protection such as water conservation measures are still viewed as impediments to economic development rather than contributors to development and as a result, incentives of economic development have impacted water resources in both towns adversely. Additionally, decision-making processes governing the management of water in both towns have largely excluded climate change considerations, and it is argued that this exclusion of climate change considerations is partly responsible for the one-sided approach to addressing water scarcity seen in both towns. The perpetuation of unsustainable economic development and failure to account for climate change in the planning and policy processes of local governments in the area of water management points to the presence of several technological, structural, financial, and political barriers to the planning and implementation of integrated strategies for adaptation to water scarcity in Dharamshala and Leh. But there are several measures that the local governments of Dharamshala and Leh can take to overcome these barriers, even in the absence of external aid, indicating the presence of low-hanging fruit that can be picked as a first step towards adaptation.

Chapter 2: Literature Review on Adaptation to Climate Change

In order to situate this thesis within the broad field of climate change adaptation, and establish its relevance to current discussions on addressing the impacts of climate change, an overview of various aspects of climate change adaptation is provided as context in this chapter. Firstly, a summary of the general impacts of climate change is presented, followed by a discussion on the consequent need for adaptation, the desirable characteristics of adaptation, the current status of adaptation, barriers to adaptation, and typical drivers of adaptation in local governments. Additionally, background is provided on the roles of various stakeholders in climate adaptation, along with an overview of the different scales at which adaptation can take place. The purpose of introducing literature on stakeholder roles and scales of adaptation is to highlight that at the sub-national scale, while it is local governments that are probably the most appropriate actors that should be responsible for facilitating climate adaptation, and while adaptation efforts are most effective when initiated at the city scale, the supporting roles played by other stakeholder groups like the private sector, non-profit organizations, academia, or community members, and the lessons learned from other scales of adaptation (i.e. individual, household, or community-based adaptation) are complementary to the roles of the local government. This literature has high relevance for the two case-studies analyzed in this thesis, as there is evidence of various stakeholder groups attempting to adapt to water scarcity within their means, especially in the absence of concerted adaptation led by the local governments in these towns. Lastly, Chapter 2 briefly introduces the concept of extreme cases, which are relevant to this thesis as extreme cases focus on a specific kind of climate change impact (water scarcity) in a specific type of location (glacier dependent towns). The literature on extreme case-studies also serves as a backdrop to the next chapter, which presents a review of specific impacts of climate change on mountain systems and water resources of glacier-dependent urban systems.

Impacts of Climate Change

The validity and predictions of the science of climate change continue to be questioned by climate skeptics. However, climate change has been declared unequivocal by the IPCC in its Fourth Assessment Report, and its "impacts are already being observed in all sectors – food, water, health, and energy" (Schipper, et al. 2008).

For example, precipitation, temperature, and water availability for agricultural purposes have been and will continue to be affected in many parts of the world as a result of climate change (Schipper, et al. 2008). This will cause agricultural productivity to decline by a third by 2050 (Ehrhart 2008). Similarly, impacts on health are on the rise due to poverty and the limited capacity of certain population groups to access health care (Schipper, et al. 2008). It is believed that climate change will cause an increase in diarrheal disease, cardio-respiratory diseases, and altered spatial distribution of some diseases like dengue due to warmer average temperature (Satterthwaite, et al. 2007). Studies also show an increase in all climate-related disasters such as storms, floods, heat-waves, droughts (De Sherbinin, et al. 2007) and cyclones (Ehrhart 2008). Under these circumstances, extreme weather events can generate new health hazards and cause disruption to existing health services, which in turn would result in increased incidence of diseases. Thus, industries, settlements, and societies located in areas already prone to extreme weather events, or areas dependent upon climate-sensitive resources are facing adverse impacts of climate change (Schipper, et al. 2008).

The availability of water has been and will be affected in many ways by climate change. For example, changes in the quantity, timing, intensity and duration of rainfall as a result of climate change will contribute to greater water stress in many regions of the world, with greatest stresses occurring in areas already suffering water scarcity and affecting low-income groups in particular. Additionally, water scarcity will be experienced during seasons when the availability of water is most critical for survival (e.g. summer) and/or sustenance of livelihoods (e.g. prior to crop sowing) (Satterthwaite, et al. 2007).

Regions across the world identified as water shortage hotspots are sub-Saharan Africa; south Asia (particularly Afghanistan, Pakistan and parts of India); and south-east Asia (particularly Myanmar, Vietnam and Indonesia). The number of people who will be impacted by water scarcity is estimated to reach 5 billion by the year 2025, and climate change will account for roughly 20% of this growth in scarcity (Ehrhart 2008).

It is predicted that a reduction in local water sources will lead to increased demand on regional water supplies. Changes in precipitation patterns may lead to reductions in river flows and falling groundwater tables, and cause saline intrusion in rivers and groundwater in coastal areas. Detected declines in glacier volumes due to reduction in the precipitation of snow will reduce river flows at key times of the year, causing substantial impacts on water flows to mountain cities (Satterthwaite, et al. 2007).

Need for Adaptation in Urban Areas

Given these impacts, it is important to consider the scale at which tangible effects of climate change will be seen, and the geographic locations and population groups that will be the most affected by climate change. It has been discussed in literature that urban agglomerations like cities and towns are especially vulnerable to the impacts of climate change on account of their location and population (De Sherbinin, et al. 2007). Cities are the engines of economic growth, and in developing countries, cities and towns attract thousands of migrants every year. The last fifty years have seen a 600% increase in the urban population of developing nations and currently, a third of the world's population lives in urban areas of developing nations (Satterthwaite, et al. 2007).

Not only has there been an increase in general urban populations in the last fifty years, but also in the number of urban dwellers living in poverty. These population groups lack basic infrastructure and services that should protect them from environmental hazards. It is estimated that a billion urban dwellers live in overcrowded housing in informal settlements without adequate provision for piped water, weather-proof roads, drains or electricity (Satterthwaite, et al. 2007). These urban dwellers have a limited capacity to finance services, and their landlords have no incentive to invest in better housing or infrastructure. Low-income urban dwellers also do not have the capacity to move to better serviced locations because of lack of alternatives, or the need to remain closer to their income source (Satterthwaite, et al. 2007).

The primary increased risk from climate change in cities is due to an increase in the frequency and magnitude of extreme climate events. The cities most at risk are those where these events are already common. Additionally, for any city, the scale of the risk from extreme climate hazards depends on the quality of infrastructure in that city, the level of preparedness among the city's population, and emergency services (Huq, et al. 2007). Within cities, it is the poorest urban dwellers that are at greatest risk from the direct and indirect impacts of climate change. This risk is brought about by the failures of local and national governments to provide infrastructure for disaster reduction and preparedness, as well as the low adaptive capacity of low-income groups (Laukkonen, et al. 2008). Thus, it may be surmised that tangible impacts of climate change are most conspicuous at the urban scale.

Characteristics of Adaptation

Given the speed at which climatic changes are occurring, and the nature of their impacts, it is imperative that the vulnerability of impacted areas and populations to climate change be reduced and their capacity to cope with climate change be improved (UNFCCC 2007). This has given rise to the concept of adaptation in climate change action. Adaptation to climate change is based on the premise that the earth is already committed to some degree of climatic changes regardless of future efforts to curb greenhouse gas emissions that are causing climate change. Adaptation is defined as "adjustments in natural or human systems in response to actual or expected climatic changes or their effects, which moderate harm or exploit beneficial opportunities" (IPCC 2007). Adaptation to climate change can take on many forms. For example, it can be reactive or anticipatory, private or public, and autonomous or planned. Options for adaptation could range from technological innovations to policy/planning action to individual behavioral changes (IPCC 2007).

The broad definition of adaptation to climate change makes it challenging to interpret its scope in operational terms. Current literature on adaptation offers various view-points on the characteristics that adaptation should encompass. For example, one school of thought is based on the premise that adaptation has clear synergies with economic development, poverty reduction, and disaster management, and therefore, should not be considered in a vacuum. Another view-point is that adaptation to climate change should be mainstreamed into development planning at international, national and sub-national scales (Schipper, et al. 2008). In general, however, it is agreed upon that the implementation of adaptation measures is most appropriate at the local scale, where the most tangible impacts of climate change occur, depending on factors such as climate and geography, governance systems, housing realities, infrastructure, resource accessibility, and the incorporation of traditional local knowledge in decision-making (Laukkonen 2008). There also appears to be a consensus on the view that climate change should be considered in short-term as well as long-term planning given the various temporal scales of the impacts of climate change. Lastly, it has been widely accepted that adaptation to climate change will require considerable funding beyond what is currently being invested in development planning, poverty reduction or disaster management (Schipper, et al. 2008).

Current Status of Adaptation to Climate Change

In light of the normative definition of adaptation to climate change (as represented in literature), it is essential to provide a background on the current status of adaptation planning and implementation worldwide to evaluate if adaptation responses on the ground are following what is prescribed in theory. Studies indicate that policies related to climate change mitigation[2] have a much longer implementation history and stronger government support as compared to adaptation policies. There is some growing evidence of concerted adaptation initiatives spearheaded by the government recently because of the increasing public interest in the impacts of

[2] Climate change mitigation is defined by the IPCC as action taken explicitly to reduce the sources of greenhouse gas emissions or enhance the sinks of greenhouse gases with the explicit goal of preventing future impacts of climate change (IPCC 2007).

climate change. However, adaptation policies have yet to proceed beyond planning and preliminary discussion in most national and sub-national governments (de Oliveira 2009).

Certain trends can be observed among the government-initiated climate frameworks that do exist today in certain nations, states or cities. In terms of implementation of climate policy, the vast majority of governance systems at the national, state or local scales seem to give higher priority to mitigation than to adaptation. This trend is quite puzzling, especially in the case of local governments, since they have a vested interest in issues like health, infrastructure, and food risks, and how each of these will be impacted by climate change (Betsill, et al. 2007). Yet, the need to reduce vulnerability to climate change in most sub-national or national governments is not well established (Huq, et al. 2007). For example, a survey of local authorities in England and Wales conducted in 2003 reveals, that despite the efforts of the UK Climate Impact Programme (an initiative that helps organizations plan and implement adaptation strategies) in reaching out to these authorities, 68% of local authorities had not considered climate change in their plans, and only 4% had developed strategies for adaptation.

Among the case-studies across the world that have shown some degree of effort to reduce vulnerability to climate change impacts, a correlation has been made between an improvement in the general competence, capacity, and accountability of the local governments and an improvement in their adaptive capacity. In other words, general improvements in the efficiency of local government operations have led to automatic ancillary enhancement of adaptive capacity. For example, according to Satterthwaite et al., the local governments of Porto Alegre and other cities in Brazil, through improvements in their social and environmental programs, have improved their sensitivity towards the needs of low income groups and the need for environmental protection respectively. This has resulted in an automatic improvement of their adaptive capacity to possible impacts of climate change like extreme events.

In addition to the aforementioned local governments that have shown indirect improvements in adaptive capacity, there are examples of local governments that have taken explicit actions to mainstream climate change into their future planning. For example, in Australia, at the local scale, the kinds of actions being undertaken for climate change adaptation include changing infrastructure and disaster plans to include forecasts for climate change, planning for larger river floodplains, protecting wetlands in areas likely to see increased severe storm events from climate change, providing corridors for species movement as climate change will cause species ranges need to change, and modifying building codes to reflect the need for more natural cooling and the need for lowering heat island effect (Hamin, et al. 2008). Other evidence of the explicit incorporation of climate change in future policy/planning includes measures taken to drain a glacial lake in Nepal for flood prevention, change livelihood strategies of the Inuit in Canada in response to permafrost-melt, increase the use of artificial snow-making in the Alpine ski industry in Europe, Australia, and North America, and account for sea-level rise in the design of infrastructure in Canada (Adger, et al. 2007).

In recent years, recognition of the challenges involving top-town forms of adaptation has given rise to an alternative bottom-up approach called Community-Based Adaptation (CBA). CBA is defined as "action by or for a community to alleviate or respond to the negative impacts of climatic changes in order to maintain human security and enhance levels of social and economic development" (Sebates-

Wheeler, et al. 2008). A specific method often used in the CBA approach is that of Community-based Risk Assessment (CRA), the goal of which is to assess hazards, vulnerabilities, and capacities with the ultimate goal of reducing risks via community-led measures (Van Aalst, et al. 2007).

There appears to be a slowly increasing application of scattered CBA and CRA by civil society actors in various regions of the world (van Aalst, et al. 2008). However, the theory and practice of CBA and CRA are still in their formative years, and there is not a lot of literature available on the evaluation of the effectiveness of methodologies and risk-reduction strategies used by these methods to help communities adapt to climate change. Nonetheless, the few reports available on CBA and CRA suggest that these bottom-up approaches do provide potentially valuable tools for climate change adaptation. Even though they may not be sufficient conditions for managing all aspects of climate risks, they are contributing to climate change adaptation, and could play a larger role if employed more systematically (van Aalst, et al. 2007).

Thus, in summary, coordinated adaptation measures that explicitly account for climate change, although still in their infancy, are being planned and implemented on a limited basis mostly in developed nations, but in some exceptional cases, in developing nations. Additionally, the lack of coordinated adaptation at the local scale has given rise to a bottom-up community-based adaptation approach. However, questions still exist about whether this approach can be more widely applicable or scaled up. In general, it can be said that these two forms of adaptation have been made possible as a result of the participation of various combinations of public, private, and civil society actors through policies, advocacy, investments in infrastructure and technologies, or behavioral change. Lastly, theories on how best to integrate adaptation into other agendas like economic development, poverty reduction and disaster management are still emerging. Since most literature on climate action have examined the ways that local and national governments address climate change via mitigation, there is limited understanding of whether and how governments are planning for the impacts of climate change (Betsill, et al. 2007).

Barriers to Coordinated Adaptation

The status of adaptation at the local, national, and international scales raises questions about factors that might be hindering effective integration of climate change adaptation into planning and policy. Following are some commonly cited barriers to concerted climate change adaptation, particularly at the local scale:

Firstly, many sub-national government administrations lack the autonomy to take action in policies that address climate change (de Oliveira 2009). Moreover, they may not have the institutional capacity, technical capability or the financial resources necessary to plan or implement measures concerning climate adaptation policies (Betsill, et al. 2007). In fact, at times, even a high adaptive capacity (seen in high income nations) does not necessarily translate into action that reduces vulnerability, as evidenced by the lack of preparedness in facing Hurricane Katrina in New Orleans, or the high levels of mortality caused by heat stress in Europe (Adger, et al. 2007).

Secondly, local governments may be occupied with other demands, interests, or challenges and therefore, may not consider climate policy as a high priority. For example, a case study from Sweden concludes that one of the major barriers to the consideration of climate adaptation in local governance is the uncertainty of climate impacts, which is weighted against actions that yield short-term economic benefit, like building waterfront housing in areas potentially vulnerable to flooding (Granberg, et al. 2007). The perceived low priority of climate change stems from the lack of linkage between the agenda pushed by climate change adaptation, and the agenda of other priorities such as poverty reduction, or economic development. The synergies between adaptation and these other priorities are not apparent to local governments due to the way most climate adaptation literature is currently packaged, as this literature primarily stems from environmental concerns or priorities, and therefore, there is not an adequate focus on human security and socio-economic development, or how the goals of these other agendas can be aligned with adaptation (Sebates-Wheeler, et al. 2008). Thirdly, since climate policy (particularly mitigation) has traditionally been formulated in a centralized, top-down fashion, local governments tend to rely upon the national government to legitimize decisions about adaptation policies and offer guiding principles for adaptation (Betsill, et al. 2007). However, the dilemma with this transfer of responsibility to national governments is that a comprehensive strategy for adaptation at the national level is inappropriate because of the diverse nature of climate impacts at the local level, and the consequent need for customized solutions to local impacts (Granberg, et al. 2007). Thus, the success of adaptation depends on strong local governance, which is often lacking in areas that require adaptation the most.

Typical Drivers of Successful Adaptation

One possible manner in which barriers to concerted adaptation may be overcome is by learning from case studies that have demonstrated success in coordinated adaptation planning and implementation. Evidence indicates that climate change is seldom the primary driver behind adaptation initiatives seen thus far. Instead, adaptation has been achieved in conjunction with resolving other issues, and therefore, the benefits of climate change adaptation are, more often than not, a positive by-product of activities aimed at addressing other local problems (Storbjörk

2007). This suggests that the success of climate adaptation policies is dependent on the extent to which they can be integrated with other policies that address other agendas, particularly sector-specific policies like water, housing, land use and transportation (de Oliveira 2008).

Other drivers that have been identified in case studies of successful adaptation initiatives at the local level include internal pressure exerted by local constituents demanding protection from natural disasters, a desire shown by local governments to pursue a secure and climate-resilient development path, and a desire shown by governments to enhance their reputation by demonstrating leadership in climate action (Sippel, et al. 2009). But the primary motivation for cities that have accounted for climate change has been actual or perceived vulnerabilities to the adverse effects of climate change like extreme weather events. It can be summarized from existing literature that motivations for adaptation fall into broad categories like 'economic', 'informational', 'institutional', 'political/cultural', and that these motivations depend on characteristics of cities; i.e. it matters if the cities are in developed or developing nations, and if the overlying infrastructure for environmental or climate-related regulations is developed or undeveloped (Sippel, et al. 2009).

Given this general overview of drivers of climate adaptation, it is useful to look at specific examples of city governments that have successfully reduced vulnerability to climate risks. Two examples of such city governments are Manizales in Columbia, and Ilo in Peru. The city of Manizales mitigated the risks posed by an expected increase in the frequency and intensity of extreme weather events to its low-income population by preventing the growth of low-income settlements in dangerous locations, and offering low-income populations improved standards of living in alternative locations via affordable green housing. This was a joint effort among the local government, universities, NGOs, and communities, and the primary trigger leading to this effort was uncontrolled population growth in the city, degradation of environmental quality, and unsustainable use of resources such as land and water. Thus, the reduction in climate risks from extreme weather events was achieved as part of a larger program to improve environmental quality and promote sustainable use of resources in Manizales in a manner that engaged various city departments, community organizations, and the public.

Similarly, in Ilo, it was the political environment, conducive to the implementation of pro-poor policies, that enabled the city to reduce climate risks by improving the living conditions of the population and the quality of the environment. Improvements were made in services such as water, sanitation, electricity, waste collection, and public space. In this case, the trigger was an anticipation of future population growth in Ilo, and recognition of the need to support the low-income population in acquiring affordable housing in order to achieve sustainable urbanization. Thus, neither of these cities was driven by climate change considerations, but they illustrate the ways in which adaptation can be achieved as a collateral benefit from other agendas, thereby highlighting the desirability of integrating climate change policy with other policies such as poverty reduction and disaster mitigation (Satterthwaite, et al. 2007).

Another prominent factor contributing to the successful formulation and implementation of climate policy, as shown by case studies, is strong intra- and inter-governmental coordination and innovation. Additionally, the presence of specific institutional incentives to facilitate the integration of climate change measures into sectoral policies also seems to be vital. Examples of such incentives or mechanisms include national subsidies or funding from international organizations (de Oliveira 2008).

Roles of Key Stakeholders in Adaptation

In cases where successful adaptation measures have been taken, there is value in identifying the stakeholders who have played a crucial role in mobilizing adaptation efforts. Given that the impacts of climate change are primarily local, it seems appropriate that local authorities (i.e. local governments or municipalities) assume leadership in facilitating responses to climate change (Wilbanks, et al. 2007). Local government plays a key role in providing the information about current and likely future risks and providing frameworks that support individual, household, community and private sector adaptation (Satterthwaite, et al. 2007).

Literature suggests that action on climate change adaptation must be at least partially attributed to the presence of key political or management leaders who have appreciation for this issue. In other words, climate champions are needed to carry forward the agenda of climate adaptation. These could be mayors, or other local politicians who can allocate resources to investigating climate change impacts, and identifying responses (Penney, et al. 2007).

Institutions within the local government that contribute to decision-making are government departments, transportation authorities, utilities, and conservation authorities. These stakeholders have specific areas of expertise like water, sanitation, energy, or transportation; and are therefore equipped to assess how climate change might impact the sectors they are responsible for (Penney, et al. 2007).

It has also been cited in literature that the complexities of planning for adaptation necessitate cooperation from sectors beyond just the local government. As a complement to the central role of local governments, higher levels of governance also need to be engaged because of the nature of adaptation measures. Adaptation generally requires substantial amounts of investment, and adaptation projects do not yield opportunities for protecting resources directly like mitigation projects do. As a result, adaptation projects can often be beyond the capabilities and resources of local governments and therefore, it has been recommended that local governments should make an effort to integrate local adaptation measures with national government frameworks to generate financial, technical and institutional resources (de Oliveira 2009).

The role of civil society in mobilizing climate adaptation has the potential to be significant, even though the responsibilities of this sector with regard to adaptation relative to that of the local government are contested. History has shown that organized civil society can be an influential force in keeping governments accountable and leading them to implement environmental policies via protests, legal action or even partnerships. In fact, environmental non-government organizations (NGOs) were instrumental in spearheading environmental regulation in developed nations in the 1960s and 1970s (de Oliveira 2009). In general, most local environmental NGOs have focused on local environmental issues like air and water pollution, solid waste, or environmental health. However, not many environmental groups are involved in explicit climate change policy at the local level, and the ones that do specialize in climate policy are larger national or international organizations like Greenpeace (de Oliveira 2009). Nonetheless, given that many local governments in regions especially vulnerable to impacts of climate change are not fulfilling their role as primary facilitators in enabling climate adaptation measures, civil society organizations (local and national) have been identified as potential initiators of planned adaptation (Satterthwaite, et al. 2007). For example, the CAVIAR consortium in the Arctic, Practical Action in Nepal and Bangladesh, Local Initiatives for Biodiversity, Research and Development in Nepal, and the Heiveld Co-operative in South Africa are organizations that have championed community-based adaptation in the absence of concerted initiatives from the government.

Additionally, it has been observed that in cases where climate change adaptation measures have been successful, research institutions and educational institutions have played a key role in planning processes in order to translate scientific data into information that can be used effectively by policy-makers (Center for Science in the Earth System 2007).

Lastly, the roles of international aid agencies and the private sector, though disputed, are important to mention in climate change adaptation. It has been argued that the role of these two sectors is vital to the mobilization of local adaptation efforts, particularly since they serve as a financial resource. However, there is emerging literature that challenges this view, and claims that the role of both sectors in climate adaptation efforts may have been overestimated. For example, in most middle-income and many low-income nations, aid constitutes a fairly small percentage of total governmental expenditures (Brazil is a notable exception (de Oliveira 2009)). In particular, urban areas in these nations receive little attention from international aid agencies. Similar observations have been made for the private sector. Research shows that most private-sector investments since the 1990s in low- and middle-income nations have been in infrastructure for which the private sector can effectively charge its users, namely electricity or telecommunications. Unfortunately, water, sanitation, drainage, roads, and railway services are a low priority for the private sector. In general, private investments in urban infrastructure are concentrated in wealthier regions, and not in regions where investments are needed the most.

Therefore, there are significant questions about how private investments and foreign aid can have a major role in investing in infrastructure that can help populations and regions most at risk adapt to climate change. Potentially, however, their contribution to climate adaptation efforts can be significant (Satterthwaite, et al. 2007).

In light of all these sectors, it can be concluded that while local governments should probably play a central, facilitating role in enabling climate adaptation, other sectors will likely have responsibilities in ensuring successful implementation of climate change adaptation measures. A strong coordination of activities at the local level driven by NGOs, research institutions, the private sector, and all levels of government will be necessary to achieve effective, concerted adaptation to climate change (Schipper, et al. 2008).

Relative Merits of Top-down versus Bottom-up Adaptation

The scale of adaptation planning and implementation has been a much contested issue, thereby raising questions about which scale is the most appropriate for effective adaptation. In order to analyze the relative merits of the different forms of adaptation, the nuances in what is often projected as a top-down versus bottom-up adaptation dichotomy must be explicated. The terms 'top-down' and 'bottom-up' do not just refer to the scale of governance (local versus regional or national), but also to the methods used to assess impacts of climate change or recommendations for adaptation. Scale of governance and assessment methods are, of course, related, but a breakdown of these two terms reveals that the answer to the question of which form of adaptation is optimal is not as obvious as the top-down – bottom-up dichotomy suggests.

A top-down assessment method of climate impacts is derived from the original characterization of climate change as a global issue. Under this model, organizations like the IPCC used the top-down assessment method to formulate technical guidelines for assessing climate change impacts and prescribed adaptation measures. Based on these guidelines, numerous studies (considered the 'first-generation' adaptation studies) were conducted on a national scale, and they used climate change scenarios derived from global models that were then scaled down to understand regional impacts (van Aalst, et al. 2007).

There is some merit to these studies, as they have made significant contributions to a better theoretical understanding of potential climate impacts. However, the scenarios in these studies have included only a simplified version of the local climate, and the outputs of these studies have been limited to predictions of changes in mean temperature, rainfall, and sea level. These studies are deficient in providing a comprehensive characterization of the full array of variables contributing to the impacts on a location (van Aalst, et al. 2007).

Additionally, these studies focused on future climate, and made recommendations to reduce impacts without taking into account the socio-economic, political, and environmental realities of the locality they were modeling, and therefore, any recommendations made using this scenario-driven approach were likely to be unfeasible (van Aalst, et al. 2007).

These limitations of top-down, scenario-driven assessment methods have given rise to a new breed of assessment methods. These methods assess vulnerability to current climate variability (as opposed to future variability), and enable the formulation of adaptation strategies, policies, and measures based on actual experience at different scales. Thus they are based on actual, empirical observations of current climate risks and how communities cope with them. Local experience and knowledge can be included in these methods, and this means that local stakeholders are involved. Moreover, this approach includes information beyond just climate parameters, like demographic, socio-economic and political implications (van Aalst, et al. 2007). CRA is an example of such bottom-up assessment methods. It is a tool used in CBA by civil society organizations. However, CBA has not been widely employed by local governments as an adaptation strategy (Sebates-Wheeler, et al. 2008).

Now that assessment methods have been described, the scale of governance becomes relevant, particularly if the goal is to determine an optimal scale and type of adaptation planning. The most obvious argument for national-level adaptation planning is that national governments have better access to institutional, technical and financial resources and are better equipped to undertake large-scale infrastructure projects. Additionally, if adaptation measures necessitate modification of existing policies or regulations, or the adoption of new ones, it is the national government that has the authority to formulate or change polices or regulations (UNFCCC 2007).

However, there is growing consensus that adaptation is better planned at the local level (i.e. the municipality scale), particularly since implementation would take place at this scale. The reasons behind this school of thought are that municipal governments have certain responsibilities like provision of services, creating employment, eradicating poverty, etc. Since climate change is likely to impact all of these issues, it makes sense for local governments to understand the consequences of climate change and play an active role in determining risks and deploying adaptation measures (Naidu, et al. 2006). Additionally, it is local governments that are most familiar with the characteristics of their municipalities and the challenges faced by them, and therefore, locally generated solutions are more likely to meet the needs of constituents (Laukkonen, et al. 2008).

Given all these relative advantages and disadvantages, some generalizations can be made. It seems that while bottom-up adaptation assessments provide useful outputs, their application has been limited to scattered project-level adaptation initiated by community organizations. It fails to deliver city-scale benefits, which, literature suggests, is best achieved at the local government scale. Having said that, there might be potential for local governments to use methods prescribed by CBA to effectively plan and implement adaptation. Adaptation efforts at the local scale would ideally be a part of a national framework which creates a policy environment conducive to adaptation and allows smooth transfer of resources from top to bottom.

Literature on Extreme Cases in the Context of Climate Change

In consideration of the fact that climate change is already upon us, and impacts of climate change are already being perceived in some parts of the world, it is useful to review studies on cities or regions that have shown especially pronounced impacts of climate change. These case studies, which can be categorized as extreme cases (Yin 1994), represent the critical test of theories that have been formulated in climate change literature, and in some ways, highlight most explicitly the upper limits of the magnitude of climate change impacts. Glacier-dependent settlements fit this description of extreme cases for three reasons. Firstly, it has been suggested that the rates of warming in mountain regions such as the Himalayas are higher than the global average, which means that the impacts of climate change in these ecosystems are more pronounced than other parts of the world (The World Bank 2008). Secondly, the downstream urban systems, which are reliant on the natural services provided by glacial systems, are impacted more strongly than other parts of the world because they are uniquely adapted to their environment, and their economy depends more directly on the natural assets of the ecosystem within which they are embedded

(H. Singh). Lastly, the impacts of climate change on glacier-dependent cities are often manifested as extreme forms of already existing threats, such as water scarcity (Rogers 2010).

Thus, the study of glacier-dependent cities offers useful insights into the kinds of impacts that can be expected from climate change, barriers faced by these cities in effective adaptation to climate change, and possible solutions that can be applied to other regions of the world which are likely to face similar threats. With this in mind, the following chapter presents in greater detail, a review of climate change impacts on mountain systems and glacier-dependent cities.

Chapter 3: Mountain Systems and Glacier-dependent Cities

Among the cities of the world facing climate change impacts, cities dependent on melt-water from glaciers and snow-pack (hereinafter referred to as 'glacier-dependent cities') present an interesting category. It is estimated that melt-water from glaciers and snow-pack sustains approximately one-sixth of the world's population. Glacier-dependent cities, over the years, have become adapted to their location, climate, and availability of natural resources (Eriksson, et al. 2009). However, climate change has disrupted the balance of nature that these cities rely upon for sustenance. In order to understand how climate change has affected glacier-dependent cities, it is first important to gain an understanding of the impacts of climate change on mountain ecosystems that support these cities.

Impacts of Climate Change on Mountain Regions

Recent research has shown that climate change will be more pronounced in high-elevation mountain ranges compared to other regions of the world. Specifically, mountains that extend into the troposphere have been warming much faster than adjacent lowlands (The World Bank 2008). For example, in the Andes, glaciers at an elevation of greater than 6000 meters are expected to experience greater warming than those at lower elevations (The World Bank 2008). Similarly, most glaciers in the Himalayas and the Tibetan Plateau region are located in the 4000-7000 meter range, and warming in these areas has been greater than the global average for the past 100 years (UNEP 2009). This warming in mountain systems has been linked to various forms of weather variability in these regions such as changes in wind patterns, pressure systems, and the strength and timing of rainfall. Warmer temperatures have caused a greater percentage of total precipitation to fall in the form of rain as opposed to snow in various mountain regions of the world. Moreover, total precipitation has also been affected, increasing in some regions while decreasing in others. Warming has also been shown to cause winters to become shorter (Eriksson, et al. 2009). Another consequence of climate change is glacial recession, which results from a decrease in precipitation in the form of snow, and increase in temperature. Glacial recession can potentially destabilize slopes, causing extreme events like landslides. Melt-water from glaciers, along with heavy rainfall, can trigger flashfloods and debris flows, and is responsible for glacial lake outburst floods (GLOFs). Climate change is also impacting the extent of permafrost in mountain regions, the integrity of which is critical to mountain ecology, slope stability, erosion processes and downstream hydrology (Eriksson, et al. 2009).

All of these impacts on mountain systems have strong consequences for the integrity of the mountain environment and the survival/livelihoods of human settlements in these systems. For example, climate change will influence the geographic distribution and type of natural vegetation native to mountain systems. Both plant and animal species are expected to move to higher elevations and might even face habitat loss and extinction. Other natural processes like sediment transport and green-water[3] flows are likely to be disrupted (Eriksson, et al. 2009).

Additionally, climate change will affect people's livelihoods in mountain regions. Firstly, the quality and productivity of farming and pastoral land will be adversely impacted. Additionally, there are direct and indirect implications of climate change for human health, because of climate-related hazards like flooding, spread of infectious diseases in previously immune regions, or effects of malnutrition resulting from crop failure (Eriksson, et al. 2009). Industries like hydropower and tourism,

[3] Green-water is defined as the water supply for all non-irrigated vegetation, including forests and woodlands, grasslands and rain-fed crops. It is the water in the root zone of soil, and is therefore different from water available in rivers, lakes and ground water aquifers (FAO 1996).

which rely on the natural assets of mountain regions, will suffer as a result of climate change (The World Bank 2008). Lastly, infrastructure such as roads, buildings, water-supply systems, sewage and drainage systems, bridges, and power-plants will be at risk due to the possibility of impacts like flash-floods (Eriksson, et al. 2009).

However, perhaps one of the most significant impacts of climate change seen in mountain systems, which has strong implications for drinking-water availability, is that on surface-water runoff (i.e. discharge of water in surface water-bodies like streams and rivers). This chapter focuses on this particular impact and its implications for downstream human settlements.

Factors Regulating Runoff and Effects of Climate Change on these Factors

Two factors regulate total and peak runoff, the first of which is precipitation (rain or snow). Mountain regions typically show regularity in the quantity, intensity, and spatial/temporal distribution of the rain or snow that they receive. Changes in these properties of rain and snow, or their proportion impact runoff directly. It has been predicted that climate change in mountain regions impacts the properties of precipitation such that precipitation will occur more in the form of rainfall compared to snowfall, and the spatial and temporal properties of rainfall will change in that it will become more polarized and extreme. Consequently, surface runoff is expected to become polarized and extreme, i.e. reduced during the summer, and increased or more intense during the wet season and winter (Middelkoop, et al. 2001).

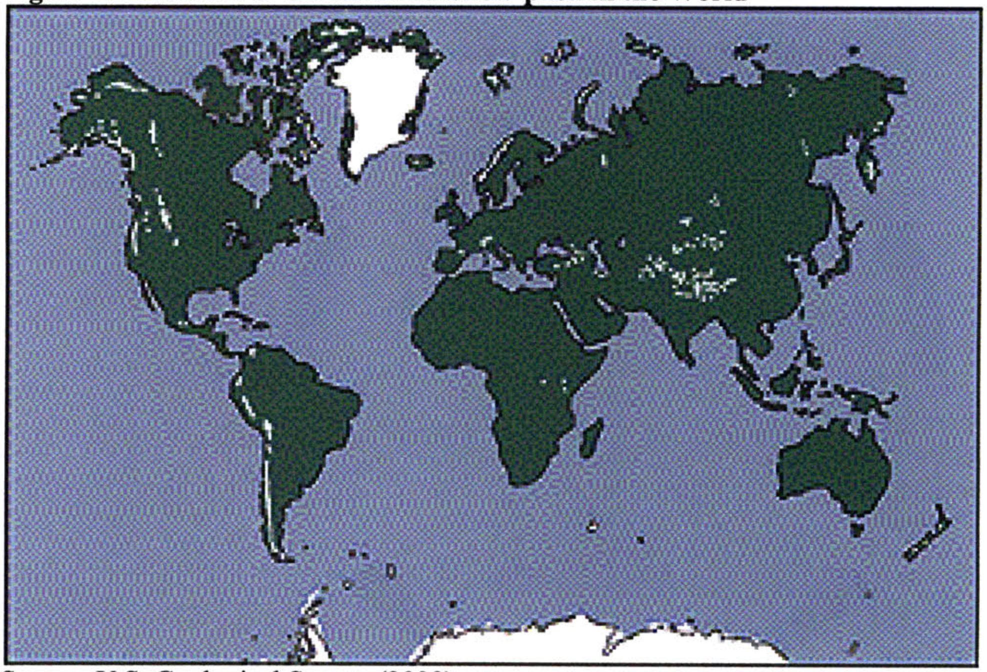
The other factor affecting average and peak runoff is the melting of glacial and snow cover. Glacial and snow-pack melting impact runoff in different ways, and it is important to differentiate between the two in order to avoid generalizations about the relationship between water availability and melting of snow. Therefore, a background is provided on glaciers and snow-pack, followed by an explanation of how their melting affects availability of water.

A glacier is a slow-moving body of ice which exists on land and is formed through the compaction and subsequent re-crystallization of snow. Glaciers require very specific climatic conditions, and are found in regions of high snowfall in winter and cool temperatures in summer. These conditions ensure that not all of the snow accumulating in the winter is lost during the summer. The two broad types of glaciers are mountain glaciers and continental glaciers (ice sheets) (de Blij, et al. 2004). This thesis focuses on mountain glaciers (which are defined as glaciers that are confined by valley walls). Mountain glaciers exist on all of the world's continents, except for Australia (de Blij, et al. 2004).

Snow-pack, on the other hand, is the amount of snow that falls in a mountain region in a given season. Snow-pack, by definition, is an unconsolidated mass of snow, and occurs in regions where the summers are warm enough to cause most of the accumulated snow to melt. In snow-pack fed mountain regions, there is a state of equilibrium, where snow accumulation through precipitation equals losses through melting, evaporation, and sublimation (Pidwirny, et al. 2008).

Figure 1 shows a map of all the regions in the world where glaciers and snow-pack exist (USGS 2010). The white areas in the figure show glaciers and ice sheets around the world. The white spots in the oceans are islands where glaciers are found.

Figure 1: Locations of Glaciers and Snow-pack in the World

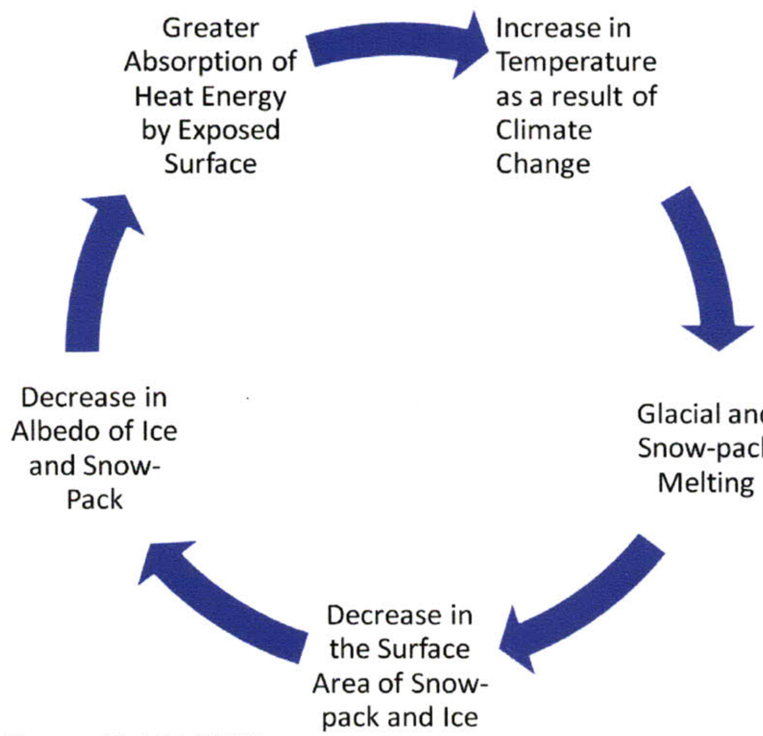


Source: U.S. Geological Survey (2009)

Thus, in addition to rainfall, glaciers and snow-pack govern the volume and variability of runoff in areas where they exist. They accumulate snow in the winter, some or all of which melts in the warm season to feed surface water-bodies like rivers or streams that supply water to human settlements that lie in their basins.

Glaciers and snow-pack are highly vulnerable to warming. Figure 2 shows the cyclical relationship between glaciers and climate, and how melting and climate change reinforce each other. An increase in temperature causes snow to melt, which reduces the surface area of snow/ice, which reduces the albedo of snow, which leads to absorption of heat energy, which reinforces melting (Knight 1999).

Figure 2: Relationship between Glacial Melting and Climate Change



Source: Knight (1999)

In contrast with seasonal snow-pack, areas with permanent glaciers impact runoff differently. In the case of permanent glaciers, initially, it is likely that melting ice and snow will increase runoff, particularly during warm and dry seasons. The rapid nature of this melting can be destructive. For example, in cities of Nepal, rapid melting of glacial ice has led to the formation of glacial lakes. The accumulation of water in these lakes has been increasing rapidly, and sudden discharge of large volumes of water from these lakes can cause glacial lake outburst floods (GLOFs) in valleys downstream, leading to vast destruction. In 1985 there was a glacial lake outburst in eastern Nepal's Dig Tsho Lake which destroyed infrastructure and took many lives (Mool, et al. 2010). In some cases, however, the rate of melting glaciers can initially be slow enough to increase the flow of water in a non-destructive manner. For example, according to reports in 2002, increased flow of melt-water was welcomed by farmers in Tanzania who relied on glaciers from Mt. Kilimanjaro for irrigation. In fact, they were growing more than they needed to survive and some of them switched to water intensive crops for export (McFarling 2002). In the last three years, however, the rate of glacial melting in Mt. Kilimanjaro is reported to have increased, and farmers have reported destructive flooding in the dry season which has submerged farms and roads (Africa News Network 2008). This shows that melting glaciers can create a false sense of security about the availability of water and that even though glacial melting leads to abundance of water in some regions in the short-term, it is destructive and cannot be harnessed. Moreover, in the long run, these regions will face acute water shortage once the glaciers melt completely.

As the glaciers disappear eventually, runoff in downstream bodies of water will primarily consist of rainfall, which would occur only during the wet season, thereby leading to reduced runoff in the dry season. In cases where seasonal (or transitional) snow has been the source of runoff, the scenarios mentioned earlier of precipitation falling more in the form of temporally polarized rain, or of precipitation decreasing overall are most likely to occur, thereby also resulting in reduced average runoff in the dry season (Nijssen, et al. 2001). There is also the possibility of all accumulated snow melting earlier than normal (due to warmer climate), implying that snow-pack would not contribute to runoff for the entire duration of the dry season. For example, it was reported in May 2009 that most of the snow-pack from the San Juan Mountains and Front Range (part of Rocky Mountains in Colorado) had melted, when typically, snow-pack in these mountains lasts until the end of summer (Streater 2009).

These effects on runoff will give rise to scenarios of water scarcity during seasons when the availability of water is most crucial for meeting basic needs as well as the needs of commercial and industrial sectors like agriculture, power generation, tourism, and recreation (The World Bank 2008).

Examples of Reduced Glaciers and Snow-pack in Mountain Systems

Table 1 shows some examples of mountain glacial systems across the world that are currently experiencing deglaciation (Combes, et al. 2003). This deglaciation is occurring at different rates. For example, the Chacaltaya glacier in Bolivia has lost 99% of its volume, and is expected to disappear completely by 2010 (The World Bank 2008). The ice fields on Mt. Kilimanjaro have lost 80% of their area during this century and are likely to disappear by 2020 (Combes, et al. 2003), and similar effects have been observed on snow-pack.

Table 1: Mountain Glacial Systems Currently Experiencing Glacial Recession

Region	**Glacial System**	**Examples of glacial sub-system**
North America	Western Cordillera	- Glacier National Park, Montana - Banff, Jasper, and Yoho National Parks, Canada - Cascade Glacier, Washington - Alaskan Glaciers
South America	Andes	- Yanamarey, Uruashraju and Broggi Glaciers, Peru - Antizana Glacier, Ecuador - Chacaltaya Glacier, Bolivia - North Patagonia Icefield, Chile - South Patagonia Icefield, Chile and Argentina
Asia	Himalayas	- Tuyuksu glacier, Kazakhstan - Ak-shirak Range, Kyrgyzstan - Urumqihe Glacier, China - Himalayan Hindukush Glaciers, India
Africa	Mt Kilimanjaro Mt Kenya Ruwenzori Mountains	- Glaciers in Tanzania, Kenya Uganda and Democratic Republic of Congo
Europe	Alps	- Hintereisferner Glacier, Austria - Gries Glacier, Switzerland - Sarennes Glacier, France
South Pacific	- Carstensz Pyramid - Central Cordelia Range, - Southern Alps	- Glaciers in Papua Province Indonesia, - Papua New Guinea, and New Zealand

Source: Combes, et al. (2003)

Relationship between Glacial Systems and Glacier-Dependent Cities

Cities have been built near sources of water supply ever since cities first came into existence. In fact, the presence of a reliable source of water has been crucial to the growth of cities. Glacier-dependent cities receive their water supply from surface or groundwater bodies that are fed by melt-water from snow-pack or glaciers. These cities have come to rely upon the natural cycle of accumulation and melting of snow for their water supply, particularly in the dry season, when there is no alternative source except for discharge in surface water-bodies or groundwater. Thus, it is melt-water that reduces the inter-seasonal variability in the availability of water in glacier-dependent cities. However, climate change is disrupting this cycle and will directly impact the water-supply sources of glacier-dependent cities. Cities in developed countries are at least partially insulated to variability in water supply because of their storage capacity and durable infrastructure. However, in developing countries, even slight or 'normal' variations in climate often have devastating effects (Nijssen, et al. 2001) on the security of water supply in glacier-dependent cities.

Status of Research on Climate Change Implications for Glacier-Dependent Cities

So far, most studies that have attempted to explicate the relationship between climate change, glacial/snow-pack melting, and its consequences have focused on hydrological impacts using climate modeling at the regional level (i.e. catchment or river basin level) (Nijssen, et al. 2001). For example, future impacts of climate change on snow-cover and runoff in two Alpine catchments (the Inn catchment and the Dischma catchment) were modeled by Bavay, et al. (2009). Similarly, Benestad and Haugen (2007) developed a regional model of climatic features in Norway in order to understand the relationship between climate change and the intensity and type of precipitation (snow versus rain). Middelkoop, et al. (2001) performed an assessment of climate change impacts on river-flow conditions in the Rhine basin. In developing nations, studies of this nature have been very limited, and have been carried out by organizations such as the World Bank in the tropical Andes (The World Bank 2008) and the International Centre for Integrated Mountain Development (ICIMOD) in the Hindu-Kush Himalayas (Eriksson, et al. 2009).

However, the link between hydrological changes and their socio-economic implications for urban settlements remains weak. In particular, it is difficult to find information that can guide local governments as they wrestle with ways to meet various needs of their city such as water demand. Among the regional modeling studies mentioned earlier, only the Rhine Basin study attempts to derive socio-economic implications and make recommendations for adaptation to expected impacts. Thus, there is limited literature on planning for adaptation to impacts of climate change on glacier-dependent cities and it seems to be prevalent largely in the developed world. For example, Ojima, et al. (1999) and Standish-Lee, et al. (2006) have documented specific socio-economic impacts and made policy/planning recommendations as well as technology-centric recommendations to address climate-induced water scarcity in snow-dependent cities of the U.S. Great Plains. There is evidence that local governments in cities like Las Vegas, Nevada (Gertner 2008); Portland, Oregan (Palmer, et al. 2002); and Aurora, Colorado (Gertner 2008) have initiated adaptation efforts based on such studies. These cities have employed various demand management strategies like economic incentives (paying consumers to remove lawns, or levying fines for leaks, or metering of water consumption), regulations (requiring businesses to install rainwater harvesting systems), and supply management strategies like finding alternative water sources (groundwater, inter-basin water transfers, desalination, recycled wastewater), and investing in better infrastructure (pipelines, reservoirs).

In the developing world, studies specifically aimed at evaluating local-scale impacts of climate change don't appear to be on the radar of local institutions, unless they are funded by international organizations, as in the case of the research done in the Tropical Andes (The World Bank 2008) or the Himalayas (Eriksson, et al. 2009), which do make a first attempt to explicate how glacier-dependent urban areas may be affected and make recommendations accordingly. For example, the World Bank has made concrete recommendations for what measures the city of Quito in Ecuador needs to take in order to prepare for water shortages resulting from reduced yields in its current water supply sources (e.g. increase storage, improve infrastructure, and find alternative sources of water). Additionally, the World Bank has also done a cost-benefit analysis of future necessary investments in water management in Quito, and an economic analysis of reduced discharge impacts on power generation (Vergara, et al. 2007). This level of detail is required for local authorities to make informed decisions, but it is unavailable to most glacier-dependent cities of the world.

Thus, it is clear that the above-mentioned cases are still an exception to the rule, as most glacier-dependent cities show little evidence of the incorporation of climate change considerations in water resource management. This is rather surprising, given that climate change is expected to alter the availability of water in these cities significantly, and a reliable supply of water is crucial to the sustenance of the economy of these cities. In fact, these cities are already experiencing water stress due to economic development, population growth, and urbanization. It has been argued that global-scale changes in population and economic development over the next decade will dictate the future relations between water supply and demand to a much greater degree than climate change (Nijssen, et al. 2001). Yet there is little evidence of reforms in the way water resources are managed in glacier-dependent cities. This indicates that the present structure of political and economic incentives for development in many of these cities continues to send perverse signals that justify degradation of their water resources. For example, in Urumqui, a city in western China dependent on the Tianshan glacier for its water requirements, growth continues to be encouraged despite the imminent threat of water shortage. While there has been some preliminary effort to ease the stress on water resources by recycling and re-use of wastewater, the extent of growth and development in the city has been called highly unsustainable by some experts (Chin, et al. 2008). Research on the future behaviour of the Tianshan glacier is currently in its infancy (it is being conducted by the Chinese Academy of Science), and the city's water planners are 'waiting for the results of this research before they can conduct their own study' to determine their course of action (Chin, et al. 2008).

The experience of Urumqui is representative of many glacier-dependent city governments (particularly in developing nations) as they take on the responsibility of meeting competing needs for economic development, better standards of living, and maintaining the integrity of their natural resources.

Based on this review of climate change impacts on glacial systems and downstream urban settlements, two case studies (Dharamshala and Leh) have been selected for more in-depth research on this thesis topic. The following chapter presents the methodology used for selecting the towns of Dharamshala and Leh as case studies, along with the research design employed while conducting fieldwork in these towns.

Chapter 4: Methodology and Research Design

Methodology

In order to understand the impacts of climate change on water resources of glacier-dependent towns at the ground level, fieldwork was conducted in two towns of northern India, namely Dharamshala in the State of Himachal Pradesh and Leh in the State of Jammu & Kashmir (J&K), in the summer of 2009. Figure 3 shows a map of the geographic locations of the 2 towns in India (Partners in Ministries for India 2009).

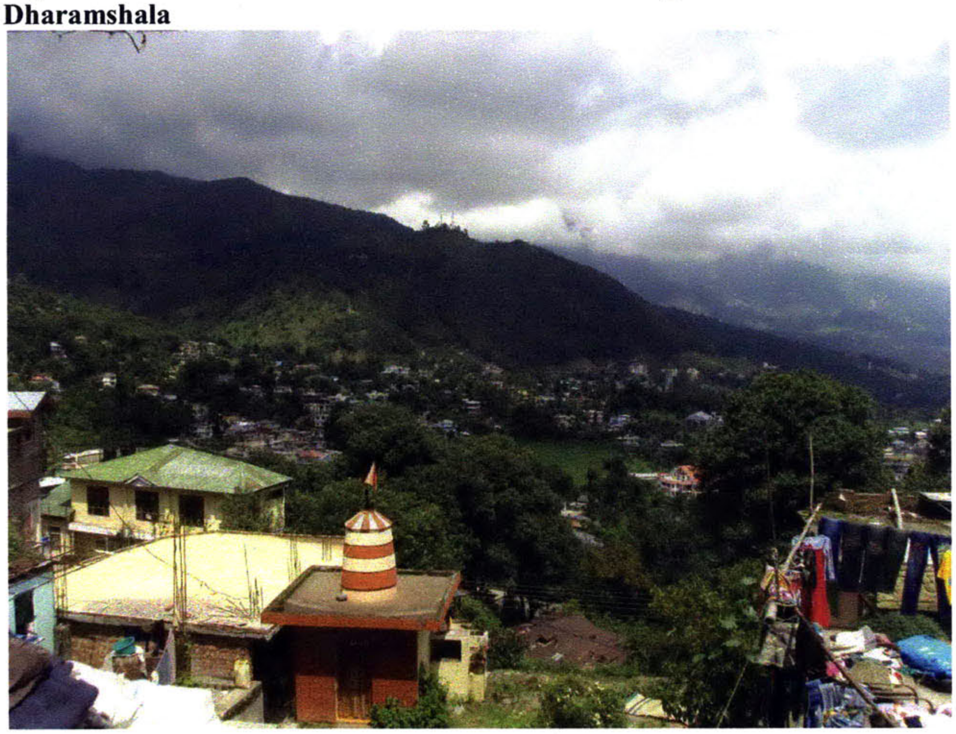
Figure 3: Geographic Location of Dharamshala and Leh

Source: Partners in Ministries for India (2009)

These case studies in India were selected on the basis of a preliminary literature review, press articles highlighting the extent of water scarcity in these towns, and phone interviews with specific organizations in the towns which confirmed the salience of water scarcity issues at the ground level.

Dharamshala is a small town in Kangra District in the State of Himachal Pradesh, and has a population of approximately 34,000. Dharamshala is one of the most picturesque hill stations in Himachal Pradesh and is famous for its dense forests, wildlife, snow-capped mountains, and pristine water-bodies (See Figure 4).

Figure 4: A View of Dharamshala and its Surroundings from Kotwali Bazaar, Dharamshala



Dharamshala is currently also the official residence of the Dalai Lama, and has been a refuge for the Tibetan government-in-exile since 1959. As a result, the town has experienced an exponential growth in its tourism industry since the 1960s, which, in addition to increasing urbanization and population growth, has amplified the demand for water in the town. Moreover, the sources of water supply in Dharamshala are reported to have shrunk recently. Traditionally, Dharamshala has been a highly rain-fed area, and receives approximately 3200 mm of rain annually, mostly during the monsoon season from June to August. However, in the recent past, this town is said to have experienced a decrease in rainfall. Furthermore, in the dry season, Dharamshala relies on accumulated snow-pack in the Dhauladhar Mountains (a part of the Himalayan Range) for its water supply. The volume of snow-pack accumulating in the Dhauladhar Mountains in winter determines the amount of melt-water available to Dharamshala in the dry season. This indicates that the accumulation of snow in the Dhauladhar Mountains is seasonal, and Dharamshala's water supply depends on this cyclical nature of accumulation and melting. Recently, there have been reports of decreases in the accumulated amount of winter snow-pack, which in turn, has decreased the amount of melt-water available to the municipality in the summer. This has given rise to problems of water scarcity during the season when the availability of water is most crucial to the survival of Dharamshala's well-being and economy. Thus, there is evidence to show that Dharamshala is already experiencing the impacts of climate change on its water resources, in addition to the stresses on water resources caused by increasing demand.

Leh is a town in the Leh District of the State of Jammu & Kashmir (J&K) in northern India, and has a population of approximately 31,000 in the winter and 45,000 in the summer. Leh is the urban center of the region of Ladakh, which is a popular tourist attraction, famous for its snow-capped Himalayan peaks and culturally preserved villages in glacial valleys. In addition to being a tourist destination, the proximity of Leh to the Indo-Pakistan and Indo-China borders also makes it a strategically important region for national security, due to which there is a strong presence of military forces in and around Leh. All of these factors have contributed to an increase in the demand for water in Leh in the last 50 years. Climatically, Leh is one of India's most arid and coldest towns (See Figure 5), and typically receives an annual average rainfall of only 50 - 200 mm.

Figure 5: A View of Leh's Surroundings

In the dry season, water from the annually replenished glacial streams and springs originating in the Khardungla glacier has been the only traditional source of drinking water in Leh. Anecdotal evidence, along with observations made by local authorities, suggests that changes have been observed in Leh's climate, one of which is low accumulation of snowfall on the Khardungla glacier in the winter. A reduction in snow-cover results in a lower recharge of groundwater and surface water, and consequently a lower discharge in springs and streams that supply water to Leh. Other impacts of climate change observed in Leh are increasing ambient temperatures that are leading to quicker melting of snow-pack, thereby shortening the number of days during which melt-water from snow is available.

In summary, both towns have traditionally relied upon streams and springs which are fed by snow-pack for their water supply. Both towns have followed similar trajectories in terms of population growth, urbanization and economic development propelled by the tourism industry. Water scarcity in both towns is believed to be brought about by economic development (increasing demand) as well as climate change (decreasing supply). There is variation in the way each of these towns has responded to water scarcity, ranging from bottom-up innovation at the individual/household level, to a relatively more coordinated level of planning at the town division level. In the absence of concerted efforts at the local, state or national government levels to help these towns adapt to water scarcity, there has recently been some evidence of scattered responses to addressing water scarcity at the sub-local level, which has been spearheaded by individual leaders, non-profit organizations and, specific town departments in charge of municipal water supply.

Given this background on the towns, the goal of the fieldwork conducted in the summer of 2009 was to understand how water scarcity has manifested as an impact of climate change in these two towns, the kinds of adaptation activities taking place (in the form of policy, planning, and implementation measures) in response to water scarcity, and the drivers of adaptive responses in these towns.

Details of Fieldwork

Fieldwork was conducted Dharamshala and Leh in August, 2009. The first two weeks of August were spent in Dharamshala, whereas the last two weeks were spent in Leh. Appendix A contains a list of the broad themes that were researched during fieldwork.

Interviews

Fieldwork was divided into two phases in each of the two towns. In the first phase, technical qualitative and quantitative data about water supply and demand was collected from the relevant water management agencies of the respective towns. Additionally, in-person interviews with open-ended questions were conducted with senior staff members and ground engineers in these agencies.

In the second phase, interviews were conducted with community leaders, research organizations and NGO staff. These interviews were conducted in English or Hindi, depending on the interviewees' preference and usually lasted for approximately an hour. A pre-determined list of questions was used during the interview, and depending on the individual being interviewed, questions were slightly modified to make them contextual. A list of questions is provided in Appendix B-I.

Limited interviews were also conducted with residential and commercial consumers of water in both towns in order to evaluate any gaps in the data presented by the water management agencies on water supply and demand. In addition to some of the questions detailed in Appendix B-I, town residents were also asked some specific questions related to their daily water consumption habits, their perspective on the water services provided by the town agencies, their coping strategies in the face of water scarcity, and their thoughts on the kinds of improvements they'd like to see in the services provided by the water agencies. The list of questions created for household interviewees is found in Appendix B-II.

Site Visits

In addition to interviews, site visits to various sources of water supply such as streams, springs, pumping wells, and ponds; storage reservoirs; and water/wastewater treatment plants were conducted under the guidance of local experts. A walking tour of residential areas within the towns was done in both towns to evaluate the condition of the local water supply infrastructure. A notebook and a camera were used to record information during the site visits, and commuting within the towns was done via taxis, buses or on foot, depending on the distance. The following two chapters present a synthesis of the information that was collected during fieldwork in Dharamshala and Leh, and from a review of literature on these two towns.

Chapter 5: Water Scarcity in Dharamshala

The Greater Himalayan Region contains the largest areas covered by glaciers outside of the Polar Regions (Eriksson, et al. 2009). Ten of the largest rivers of Asia originate in the Himalayas, and the catchments of these rivers are home to over a billion people (Hua 2009). Within the boundaries of India, the Himalayas are comprised of glaciers of various sizes, from small seasonal glaciers to extremely large permanent glaciers such as the Siachen glacier, which is the second largest outside of the Polar Region. Himalayan glaciers in India are distributed among the States of Jammu & Kashmir (J&K), Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh. These glaciers play a crucial role in regulating the drinking-water availability of northern India in addition to supporting agriculture, hydro-power production, tourism, and other industries in the region (Raina 2009).

The entire northern Indian region is experiencing population growth and rapid urbanization. This is leading to major economic and land-use changes, and exerting tremendous pressure on water resources. Additionally, climate change is expected to aggravate the existing stresses on water resources caused by these socio-economic factors in this region (Hua 2009). This calls for the need to gain a better understanding of the kinds of changes that are taking place in the hydrological systems supported by the Himalayan glaciers, and how these changes are translated into impacts on expanding urban systems embedded within the Himalayas. This is especially important since since there are multiple factors responsible for water scarcity manifesting in Himalayan settlements, namely, decreasing supplies of water resources due to climate change, as well as increasing demand due to economic development, and any future efforts to address water scarcity must take into account both these factors if the efforts are to be effective. Chapter 5 draws on the experiences of Dharamshala, a town in the State of Himachal Pradesh, which is representative of small towns in the Himalayas dependent upon seasonal snow-melt for their water requirements.

Based on anecdotal evidence and some quantitative data, it has been observed that the water resources of Dharamshala have been and will be impacted by climatic changes and urbanization. The following discussion uses Dharamshala as a case study for the analysis of possible impacts of climate change and urbanization on its water resources, and the kinds of responses that are emerging in Dharamshala from the government and other sectors to mitigate water scarcity and/or adapt to it. The scope of this analysis is limited to impacts on urban drinking water.

The first section of this chapter offers background information about the geography, climate, demographics, socio-economics, and political history of Dharamshala, followed by a historical overview of water-use and current institutional management of water resources in this town. Additionally, details about current water sources in Dharamshala, along with data on current and projected demand are described in the second section. The purpose of this information is to point out that even if climate change impacts are ignored, stresses on water resources are already present (with more acute water scarcity imminent in the future) because of various factors such as increasing population, urbanization, economic development, and inefficient institutional management of water. In other words, there are gaps between supply and demand in Dharamshala even before impacts of climate change are considered.

The third section of this chapter describes the changes in the hydrology of the sources of Dharamshala's water supply, which have been attributed to changes in the climatic parameters (e.g. snow-fall, rainfall, and temperature) that govern the water availability of Dharamshala. This section points out that climatic changes in Dharamshala will exacerbate the imminent water scarcity brought on by the aforementioned development-related factors. In the final section, evidence of responses to water scarcity from the government as well as non-government sectors in Dharamshala is examined.

Dharamshala

Geography and Climate

Dharamshala is a small town in the Kangra District in the western part of the State of Himachal Pradesh in India. Himachal Pradesh lies in the north-western region of India and is famous for its natural beauty, biodiversity, varied climatic zones, and diverse topography (Ecotourism, Himachal Pradesh 2007). Dharamshala is located in the southern spurs of the Dhauladhar range, a branch of the Western Himalayas. It is divided into upper and lower towns with a difference of approximately 457 meters (1,500 ft) between the two parts. As a result, Dharamshala's altitude varies between 1,250 meters (4,000 feet) and 2,000 meters (6,460 feet) (World Travel Guide n.d.).

Dharamshala's climate is characterized by a summer season from March to May, monsoon season from June to September, and winter season from October to February. Dharamshala receives the second-highest amount of rainfall in India (3200 mm/year) (Hotels in Dharamshala n.d.). This is because of the interplay of monsoon currents, and the sudden rise and alignment of the mountain range surrounding the town. Dharamshala is located on a ridge directly across the south-westerly monsoon currents and is surrounded on the north, north-west, and north-east by hills. This sudden ascent from the valley is responsible for heavy precipitation in this region (Rajwant 2005). During winter, particularly in the month of January, the temperature drops significantly, and the town has been known to experience snowfall (although this is extremely rare) (Sterkele, et al. 2003). On average, the temperature in Dharamshala varies from 3° Celsius to 32° Celsius (Rajwant 2005).

Demographics

Dharamshala has a population of approximately 34,036 (Department of Irrigation and Public Health 2009). The total surface area of the town is approximately 30 square kilometers (sq. km.) (Bhasin 2009) and therefore, the population density of Dharamshala is 1,136 persons/sq. km. This density is considerably higher than the average density of Himachal Pradesh, which was reported at 109 persons/sq. km in 2001 (Census of India n.d.), but much lower than that of a megacity like Delhi, which is currently 11,050 persons/sq. km (City Mayors n.d.). Dharamshala has a predominantly Hindu population, followed by Buddhist, Muslim, Sikh, Jain, and Christian minorities. This town is also a refuge for the exiled Tibetan community and therefore, a third of the total population of Dharamshala is Tibetan (Department of Irrigation and Public Health 2009).

Owing to its scenic beauty as well as its cultural and religious significance, Dharamshala has experienced a significant rise in its resident and tourist populations since the 1960s (Reddy 2008). Past population trends and future projections for Dharamshala are shown below in Table 2. This data illustrates that from 1981 to 2001, the population of Dharamshala increased by approximately 32%. This rate of population growth was lower than the regional population growth rate in the State of Himachal Pradesh, which as approximately 42% (Government of Himachal Pradesh 2008). However, by the year 2015, Dharamshala's population is expected to increase by approximately 58% of its 2009 population, thereby implying an increasing population growth rate since the 1980s. This translates into a significant increase in the demand for water by the year 2015 and beyond, which will be discussed in greater depth in the next sections of this chapter.

Table 2: Population Trends in Dharamshala

Year	Population
1901	4,755
1971	10,560
1981	14,522
1987	18,559
2001	19,124
2009	34,036
2015	53,948

Source: Department of Town and Country Planning, Government of Himachal Pradesh (1987) and Department of Irrigation and Public Health (2009)

Socio-economic Characteristics

In general, the indicators of socio-economic development in Kangra District and the State of Himachal Pradesh have been fairly positive. For example, compared to the national literacy rate of 65.38%, the literacy rate in Kangra District is significantly high at 80.08% according to the 2001 census (Government of Himachal Pradesh 2008). Similarly, the per capita income of Kangra District according to 2005 data was approximately Rs. 29,495 ($662[4]) (Government of Himachal Pradesh 2008), which is considerably higher than the national average per capita income of Rs.16,707 ($375) (Guruswamy 2004). Interestingly, Himachal Pradesh is the least urbanized State in the nation (National Inormatics Center, Department of Information Technology, Government of India 2010), which implies that a large percentage of its economy relies on agriculture. However, in Kangra Distrct, there seems to be some indicaton of a diversifying local econmy. The percentage of non-agricultural workers in the district according to the 2001 census was 40.86%, and is expected to have increased since then (Government of Himachal Pradesh 2008).

[4] The conversions from Indian Rupees to US Dollars are based on an exchange rate of 1 US Dollar equal to Rs. 44.53 as of April 18, 2010 (Yahoo India Pvt Ltd 2010).

Government and Administration

Dharamshala is the headquarters of Kangra District. In the mid-1800s, during the British rule, Dharamshala used to be sparsely populated, with only two zones of Upper Dharamshala inhabited by civilians, namely McLeodganj[5] and Forsythganj (named after two highly ranked British officers of the ruling government). Gradually, by the early 1900s, these two zones became centers of trade, business and governance in the Kangra district (NIC Kangra 2010). However, in 1905, a massive earthquake in the upper reaches of Dharamshala prompted the British government to shift the district headquarters to Lower Dharamshala, leading to greater investment in urban infrastructure in the previously neglected lower part of the town. Upper Dharamshala continued to be used as a holiday resort by the British, until India gained independence in 1947. In 1959, the Government of India granted political asylum to the Dalai Lama and the exiled Tibetan community, and Upper Dharamshala was designated as their official refuge. Subsequently, the Tibetan government-in-exile was established in McLeodganj in 1960. However, the offices of the municipality of Dharamshala are housed in Lower Dharamshala, which is also where a majority of the local residents live (NIC Kangra 2010). Therefore, the two parts of Dharamshala are quite distinct from each other. The current organizational structure in the local government consists of a Municipal Council (MC), which is the executive body of the Dharamshala Municipality, and represents a political body with decision-making power (Sterkele, et al. 2003).

In conjunction with Dharamshala's evolution from a sparsely populated, scenic hill station to a town of cultural, social, and political consequence, the State of Himachal Pradesh has struggled to create an identity and preserve its autonomy in the

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[5] The world *ganj* is often used in India as a reference to a market center or down-town which has not grown into a fully-fledged town (Kundu 1999).

Indian political system since independence. Himachal Pradesh was first identified as a centrally administered territory in 1948 after India gained independence in 1947, by the integration of 30 erstwhile princely states (NIC,H.P. State Center 2010). In 1956, it was proposed that Himachal Pradesh be merged with the State of Punjab. Ultimately, Himachal Pradesh retained its identity, but was designated as a Union Territory[6] instead of a State, and therefore, had limited legislative powers. Subsequently, as a result of the persuasion of the political leadership in the region, Himachal Pradesh was granted a Legislative Assembly and Council of Ministers (typically only seen in States) despite being a Union Territory. Finally, in 1971, Himachal Pradesh was recognized as a State under the administration of Mrs. Indira Gandhi, the Prime Minister of India at that time (NIC,H.P. State Center 2010). Since gaining its identity as a State, Himachal Pradesh has faced unique challenges in becoming a crucial player in India's booming economy. Even though Himachal Pradesh has one of the highest per capita incomes among the States of India (the per capita average State income was Rs. 33,283 ($747) in 2007 compared to the national average of Rs. 16,707 ($375) (Government of Himachal Pradesh 2008)), it is the least urbanized State in the nation, implying that its economy relies heavily on rural industries like agriculture, horticulture, and livestock production (National Inormatics Center, Department of Information Technology, Government of India 2010). These sectors have traditionally dictated the use of water in the State. However, with the advent of tourism in growing urban centers like Dharamshala, there has been an additional stress on water resources, and it is interesting to examine how water resources have been allotted in Dharamshala in response to the increasing demand for water in the domestic and commercial sectors.

[6] Union Territories are sub-national administrative divisions of India that are directly governed by the federal government and not by the state government.

History of Water Use in Dharamshala

The management structure of water resources and the trends of water use in Dharamshala have seen many changes since the town was first inhabited. It is estimated that the first piped water-supply system in Dharamshala was laid during British rule in the mid to late 1800s (the precise date is not known). This system has been expanded in stages since then, but even today, not all parts of the town have access to piped water supply (Malhotra 2009). Senior residents of Dharamshala recall that prior to the 1960s, there used to be equilibrium in the supply and demand of water in the town. There are two primary explanations for this equilibrium: firstly, the population of Dharamshala was much smaller during this period (less than 10,000 people), which indicates that the total demand for water was lower. Secondly, limited household access to convenient and piped water kept the per capita demand in check. Water supply infrastructure in Dharamshala during this period was poorly developed, and therefore, residents would often fetch water on their own from natural springs (known as *baulis*) and streams that flowed through Dharamshala. As a result, water was used frugally. For example, people would not bathe or wash clothes every day, and used pit latrines for sanitary purposes (Tandon 2009).

With the introduction and expansion of the piped water network, new uses of water that were previously not feasible became possible. For example, as awareness about hygiene and sanitation increased, residents adopted the water-intensive western model of water supply and sanitation, which included the use of septic tanks. Additionally, a growing tourist industry and rapid urbanization resulted in a greater increase in the demand for water since the 1960s (Tandon 2009).

Institutional Structure of Water Management

The institutional management of water in Dharamshala has gone through several reforms in the past 30 years. Prior to 1986, water supply in Dharamshala was governed by the Municipal Committee of Dharamshala. However, the Municipal Committee faced multiple challenges due to lack of financial resources and technical expertise, and therefore, the responsibility for managing water supply was transferred to the Himachal Pradesh State Department of Irrigation and Public Health (IPH) in 1986 (Department of Irrigation and Public Health 2009).

In terms of regulation, IPH divides Himachal Pradesh into four zones for administrative purposes, and the town of Dharamshala falls under the "Dharamshala Zone", which includes Kangra and Chamba Districts (INRM Consultants & Technology House Consortium 2006). As far as daily operational management is concerned, IPH operates under a hierarchy of engineers with an engineer-in-chief at the top, who reports directly to the honorable secretary of Himachal Pradesh, followed by a chief engineer, superintending engineers, executive engineers, and junior engineers in decreasing order of seniority (Tandon 2009). Typically, it is junior engineers who are the most familiar with the details of IPH's water supply services at the town level. However, junior engineers are primarily engaged in addressing complaints or requests, or overseeing infrastructure expansion projects as they arise (Tandon 2009). These responsibilities are extremely time-intensive, and make it difficult for junior engineers to engage in proactive planning for the improvement of IPH's water services via consultations with senior management. Additionally, the technocratic hierarchy in IPH has strong implications for how the challenge of water scarcity is defined by IPH and how it is addressed. This technocratic process of arriving at solutions is discussed in greater detail in Chapter 7.

IPH regulates water under the guidance of the Himachal Pradesh State Water Policy of 2005. The primary objective of this policy is to ensure that available water resources (surface and groundwater) are utilized in an efficient manner to meet drinking water needs and irrigation requirements of the State (Department of Irrigation and Public Health 2005). This policy is holistic in terms of its prescribed areas of water management, and contains elements that an integrated water resources management (IWRM[7]) policy document should have. For example, it emphasizes water conservation, artificial groundwater recharge, rainwater harvesting, water re-use, and sustainable groundwater use. Additionally, it also promotes water demand management, decentralized operation, private sector participation, empowerment of communities in management of resources, and gender equality in stakeholder engagement. It calls for the use of standardized information systems and databases to collect information pertinent to water resources, and investment in research and development on the viability of current and future water resources. The policy also recommends managing water resources with the water basin as a hydrological unit, and reorganizing institutional structures to suit this scale of management. There are strict guidelines in this policy for the evaluation of water resource development projects on the basis of their social, economic, and environmental impacts. Lastly, periodic audits of existing infrastructure, leakage prevention, water treatment, awareness, and education are prioritized in this policy (Department of Irrigation and Public Health 2005).

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[7] IWRM is defined as a "planning and implementation process based on sound science, that brings stakeholders together to determine how to meet society's long-term needs for water while maintaining essential ecological services and economic benefits. The principal components of IWRM are: managing water resources at the basin or watershed scale, optimizing supply, managing demand, providing equitable access to water resources, establishing improved and integrated policy, regulatory, and institutional frameworks, and utilizing an inter-sectoral approach to decision-making" (USAID 2006).

In addition to the State Water Policy, IPH follows the guidelines of a separate Groundwater Authority for the management of groundwater resources (Department of Irrigation and Public Health 2005). Similar to the State Water Policy, the Himachal Pradesh Groundwater Act takes into account the finite extent of groundwater resources in Himachal Pradesh, and prescribes measures for sustainable use of groundwater. For example, according to the Act, motorized pumping wells cannot be installed without permits, and must have an abstraction measurement device. The Act has prescribed a fee structure based on the amount of groundwater consumed, and requires certain buildings in urban areas to install rainwater harvesting structures for the purpose of groundwater recharge. Violations of this Act are punishable by law, resulting in fines and/or imprisonment (Department of Irrigation and Public Health 2005).

However, the provisions of the Himachal Pradesh State Water Policy and Groundwater Act do not easily translate into efficient implementation at the local level in the town of Dharamshala. IPH perceives itself primarily as a water-supply agency (Malhotra 2009). The following three paragraphs provide a summary of the various versions of water-supply strategies that have been formulated by this office for the town of Dharamshala:

In 1988, shortly after taking over the responsibilities for Dharamshala's water management, a new water-supply scheme was put together by IPH, which planned for a population of 30,064 up to the year 2008 at a minimum acceptable supply rate of 120 liters per capita per day (LPCD) (Department of Irrigation and Public Health 2005), an increase from 70 LPCD, which was the previously existing minimum acceptable supply rate (Tandon 2009). Infrastructure expansion under this scheme was completed in 1993-94, and a fixed-tariff pricing structure was applied in urban and rural parts of Dharamshala until 2005. Table 3 shows the fixed rates applied under this structure.

Table 3: Fixed-Tariff Monthly Pricing Structure for Municipal Water Supply in Dharamshala

URBAN		
	Domestic	Commercial
Monthly Consumption Fee in Rs.[1]	Rs. 53.34 ($1.20)[8]	Rs. 242 ($5.44)
RURAL		
	Domestic	Commercial
Monthly Consumption Fee in Rs.	Rs. 12.10 ($0.27)	Rs. 100 ($2.25)
[1]Rs. = Rupees		

Source: Department of Irrigation and Public Health (2005)

Given the differences in the tariffs for the domestic sector versus the commercial sector, and urban versus rural areas, it can be seen that IPH subsidized domestic use of water in Dharamshala. Subsidization was even greater for rural areas versus urban areas in both domestic and commercial sectors. This structure was enforced until the year 2005, after which, IPH revised the pricing of drinking water. The structure of fixed-tariff pricing of water was discarded, and tariffs based on the quantity of consumption were adopted in urban areas for both domestic and commercial sectors, and in rural areas for the commercial sector. The rural domestic sector, however, continues to be regulated under the fixed-tariff pricing, as can be seen in Table 4 (Department of Irrigation and Public Health 2010), and all sectors are still subsidized to some extent.

[8] The conversions from Indian Rupees to US Dollars are based on an exchange rate of 1 US Dollar equal to Rs. 44.53 as of April 18, 2010 (Yahoo India Pvt Ltd 2010).

Table 4: Revised Pricing Structure for Municipal Water Supply in Dharamshala[9]

URBAN	2005		2008		2009	
	Domestic	Commercial	Domestic	Commercial	Domestic	Commercial
Connection (Rs.[1])	Rs. 300 ($6.74)	Rs. 500 ($11.23)	Rs. 300 ($6.74)	Rs. 500 ($11.23)	Rs. 300 ($6.74)	Rs. 500 ($11.23)
Consumption (Rs. per KL[2])	Rs. 4 ($0.09)	Rs. 8 ($0.18)	Rs. 5.32 ($0.12)	Rs. 10.64 ($0.24)	Rs. 5.85 ($0.13)	Rs. 11.70 ($0.26)
RURAL	2005		2008		2009	
	Domestic	Commercial	Domestic	Commercial	Domestic	Commercial
Connection (Rs.)	Rs. 100 ($22.46)	Rs. 200 ($44.92)	Rs. 100 ($22.46)	Rs. 200 ($44.92)	Rs. 100 ($22.46)	Rs. 200 ($44.92)
Consumption (Rs.)	Rs. 10 per connection ($2.25)	Rs. 8 per KL ($1.80)	Rs. 13.31 per connection ($2.99)	Rs. 10.64 per KL ($2.39)	Rs. 14.60 per connection ($3.28)	Rs. 11.70 per KL ($2.63)
[1]Rs. = Rupees [2]KL = Kilo-Liter						

Source: Department of Irrigation and Public Health (2010)

To get an idea of the extent of subsidization of water in Dharamshala, an estimate of the capital, operations, and maintenance cost of water production is needed. This information was not shared by IPH, as the interviewed engineers did not have updated estimates of the cost of water services, and therefore, a national average of the cost of water production in urban areas (Rs. 15 per KL, equivalent to $0.34) is used as a benchmark for Dharamshala (Raghupati, et al. 2002). It is likely that the cost of water production in Dharamshala is lower than the national average given that its piped network runs on gravity, and spring water does not require treatment. Accounting for these factors, under the consumption-based pricing model, it is estimated that approximately 30%[10] of water production costs are recovered from the

[9] The conversions from Indian Rupees to US Dollars are based on an exchange rate of 1 US Dollar equal to Rs. 44.53 as of April 18, 2010 (Yahoo India Pvt Ltd 2010).

[10] This percentage is determined by dividing the price per kilo-liter of water (Rs. 4) by the estimated cost per kilo-liter of water production based on national statistics (Rs. 15), which is 27% and adjusting this figure based on the assumption that the cost of water production in Dharamshala is slightly lower than the national average, thereby bringing the final estimate to 30%.

domestic sector, given that this sector is charged Rs. 4 per KL ($0.09 per KL) of use. Using the same assumptions for the commercial sector, approximately 60% of cost is likely recovered, given that this sector is charged Rs. 8 per KL ($0.18 per KL).

Traditional Sources of Water Supply

Traditionally, Dharamshala has relied mostly on surface water for its needs. Examples of surface water sources include small streams (*nullahs*), medium-sized streams (k*hads*), and rivers. Water from stream sources is collected via pipes, and diverted to one of two water treatment plants in Dharamshala. The method of diversion depends on the relative location of the water source and the treatment plants. Most streams that supply water to Dharamshala originate at higher elevations in the Dhauladhar Mountains and therefore, the water from these streams is carried to the treatment plants via gravity (Tandon 2009). In addition to surface water, Dharamshala also relies to some extent on spring sources. These spring sources are considered to be generally pristine, and therefore water from springs is only chlorinated before it reaches the point of use. After treatment, the water is distributed either to individual households or public taps via a centralized water supply system, also by gravity. At the point of use, water is generally stored in overhead storage tanks by consumers who have individual household connections (See Figure 6). Generally, the pressure of the piped water supply is high enough to transport it to these tanks, which are typically installed on terraces. Those without access to individual connections collect water from public taps and store it in buckets (Tandon 2009).

Figure 6: A Roof-top Storage Tank in a Household with a Private Water Connection

On average, water is supplied for two hours per day, at various times of the day in different parts of the town. During lean periods, however, IPH adjusts its water supply by providing water for only one hour per day, or half hour per day, and at times of acute scarcity, on alternative days (Tandon 2009). Thus, water rationing has been a regularly employed strategy to deal with limited water supply, necessitating some form of storage at the household level, either in tanks, or buckets (Tandon).

As far as water quality is concerned, IPH maintains that water sources in Dharamshala are relatively pristine, and so far, no health concerns have emerged. Moreover, past studies indicate that many households in Dharamshala either filter[11] or boil their drinking water, and therefore, water quality does not seem to be a major issue of concern for the town (Sterkele, et al. 2003). In some locations, residents still have the option of getting water directly from streams or springs on their own (using

[11] This information was taken from a report on the water management in Dharamshala by Sterkele, et al. (2003), and the type of filtration was not specified in the report.

buckets), and as a rule, do, given that not all parts of the city have access to piped water (Tandon 2009). Overall, it is estimated that 86% of households in Dharamshala have individual connections, and 12% have access to public water taps (Sterkele, et al. 2003).

Based on increased demand, additional water sources have been added to Dharamshala's water supply on an incremental basis in the last ten years (Department of Irrigation and Public Health 2009). Currently, there are six main sources that supply water to the town. Table 5 lists these sources, along with the quantity of lean period discharge available in these sources and the quantity of water drawn from these sources during wet as well as dry periods.

Table 5: Traditional Sources of Water Supply in Dharamshala

Source	Available Discharge in 2006 during Lean Period (LPD[1])	Water Drawn in 2009 during Wet Period (LPD)	Water Drawn in 2009 during Lean Period (LPD)
Churan *Khad*	2,710,000	900,000	700,000
Glenmore Spring	106,670	100,000	60,000
Bhagsu Spring	325,000	300,000	260,000
Dhoop *Nullah* (Dharamkot)	400,000	300,000	100,000
Bathed *Khad*	5,284,800	4,200,000	3,000,000
Additional Water from Bhagsu Spring	-	-	700,000
Total:	8,826,470 LPD	5,800,000 LPD	4,820,000 LPD
[1]LPD = Liters per day			

Source: Department of Irrigation and Public Health (2009)

According to this table, if the average available discharge in Dharamshala during the dry season is assumed to be 8.8 MLD, and water drawn during the lean period is assumed to be 4.8 MLD, this means that approximately 54%[12] of the available discharge in the supply sources of Dharamshala was withdrawn for consumption in 2009. This gives an estimate of the extent of water stress in

[12] This calculation of 54% is derived by dividing the water drawn during the lean period (4.8 MLD) by the average available discharge during the lean period (8.8 MLD).

Dharamshala per international standards. For example, IPCC and the United Nations Environment Programme (UNEP) use an index developed by Falkenmark and Lindh (1976) which categorizes water stress based on the amount of water withdrawn in a region as a percentage of available water resources in that region (IPCC 2001). In this categorization, the regions in which over 40% of total available water resources is withdrawn are denoted as regions facing the highest magnitude of stress (IPCC 2001). Thus, the data on surface-water discharge indicates that Dharamshala faces significant water stress during the dry season.

Groundwater

It was mentioned earlier that Dharamshala has primarily relied on surface sources for its water supply, along with some spring sources that emanate naturally from the sub-surface. Until the last decade, the town had not considered extracting groundwater via pumping wells to augment its supply. However, since the beginning of the new century, IPH has installed numerous hand-pumps and motorized pumps in various parts of Dharamshala in order to extract groundwater (Tandon 2009). Records indicate that these pumps are used by government institutions such as police stations, municipal schools, and the Government College (Department of Irrigation and Public Health, Himachal Pradesh 2009). Table 6 gives a summary of the number of pumps installed by IPH in the town, along with the average daily extraction rate of each pump. The total daily extraction of water from these pumps amounts to 837,000 LPD, which is roughly 17% of the daily water supply of Dharamshala as shown in Table 5. The rates of extraction given in Table 6 are based on estimates made by senior officials in the Dharamshala Zone office, and are not accounted for in the overall water supply-demand calculations derived by IPH for the town (Tandon 2009).

Table 6: Types of Pumps used for Extraction of Groundwater in Dharamshala

Type of Pump	Number of Pumps	Daily Rate of Extraction Per Pump (LPD[1])	Total Daily Extraction (LPD)
Manual Hand Pumps	21	9,000	189,000
Motorized Hand pumps	18	36,000	648,000
		Total:	837,000 LPD
[1]LPD = Liters per day			

Source: Department of Irrigation and Public Health, Himachal Pradesh (2009)

Additionally, the data in Table 6 does not include the numerous individual motorized and manual pumping wells that have been installed by various users in Dharamshala without registering them with IPH. There is no reliable estimate on the number of private pumping wells being operated by users in the town and the amount of groundwater extracted from these wells. However, it can be assumed that given the upfront investment required to install private wells, it is probably only the wealthier households and commercial users like hotels that are currently able to avail of the benefits of private wells (Sterkele, et al. 2009).

Storage Reservoirs:

Dharamshala currently has ten municipal storage tanks located at various sites within the town. The combined storage capacity of these tanks is 3.33 million liters (Department of Irrigation and Public Health, Himachal Pradesh 2009). This storage capacity is less than the quantity of water supplied on a daily basis to Dharamshala, which, according to Table 5, is 5.80 MLD during normal wet conditions. This lower storage capacity is partially due to the fact that a portion of the water supply is piped directly from sources to the end users. However, even after accounting for this direct supply, there is still a deficit in the town's storage capacity, implying that storage tanks are able to hold less than a day's worth of water supply. This means that the town cannot store water to be prepared for unanticipated problems that could arise in the various components of the water supply system (i.e. extraction, treatment and distribution). For example, natural hazards like landslides or floods could cause damage to water infrastructure, thereby disrupting supply, and during such times, the presence of adequate storage systems is highly desirable. Additionally, limited storage capacity prevents the town from being able to store large quantities of water for use during the dry season, which is when there are limited reliable sources of water available to the town

Current and Future Demand for Water in Dharamshala

In light of the expected population growth and urbanization trends projected for the town, IPH has documented the current and projected demand for water up to the year 2015 in Dharamshala. Table 7 provides details on the distribution of users of water in the town, along with present and future demand for water (Department of Irrigation and Public Health, Himachal Pradesh 2009). These projections of water demand are based on minimum acceptable rates of consumption for each of the user categories listed in the table, as determined by the Himachal Pradesh Department of Irrigation and Public Health. From the table, it is clear that the population of Dharamshala is going to increase by approximately 58% of its current population by 2015. As a result, the demand for water will increase by approximately the same magnitude. Similarly, there is an expected increase in the number of students, employees, and visitors as well as commercial user categories.

Table 7: Current and Projected Water Demand by User Category

	2009			2015		
	Number of Units	Unit Rate of Consumption in Liters/Day	Water Demand in MLD[1]	Number of Units	Unit Rate of Consumption in Liters/Day	Water Demand in MLD
Persons	34,036	120	4.08	53,948	120	6.47
Students & Employees	11,661	45	0.52	18,483	45	0.83
Hotel Beds	592	180	0.11	940	180	0.17
Visitors	4,498	45	0.20	7,129	45	0.32
Rest Houses	385	135	0.05	610	135	0.08
Hostel Beds	633	135	0.09	1,004	135	0.14
Hospital Beds	415	455	0.19	658	455	0.30
Cinema Seats	434	15	0.01	688	15	0.01
Fire Hydrant	-	-	-	-	-	0.70
		Total	5.25		Total	9.02

[1]MLD = Million Liters per Day

Source: Department of Irrigation and Public Health (2009)

Gaps between Supply and Demand

From Table 5, it can be surmised that the amount of water drawn from traditional sources during Dharamshala's dry season (known as lean period) is 4.82 million liters per day (MLD). The present demand for water in Dharamshala, according to Table 7 is 5.25 MLD, implying a supply gap of 0.43 MLD. It should be pointed out that this calculation might be prone to high inaccuracies because it does not take into consideration the quantity of water that is unaccounted for in Dharamshala's supply network. Not all of the water drawn from the supply sources in Dharamshala is conserved as it makes its way to the point of use. A large amount of water is lost due to leakages in pipes or taps resulting from poor quality material, poor masonry, wear-and-tear, and poor maintenance. For example, Figure 7 shows an exposed leaking pipe carrying drinking water that runs across a road in a commercial area in Dharamshala. The leak has been temporarily repaired by plastic taping which is not very effective in keeping the leak in check. Additionally, Figure 8 is illustrative of the quality of masonry in Dharamshala's water infrastructure. It shows multiple water pipe-lines that run along the sides of roads, suspended on top of storm-water drains. These pipe-lines are subject to damage from rocks or heavy flooding, particularly since they are exposed.

Figure 7: A Leaking Pipe with Plastic Taping

Figure 8: Multiple Pipelines along Road-sides suspended on top of Storm-water Drains

IPH estimates leakages to be approximately 20-25% of total water drawn, but it is very likely that the leakages are as high as 50% (Sterkele, et al. 2003). Therefore the actual daily consumption of water by the domestic sector is estimated to be not much higher than 30 LPCD. Another factor not accounted for in the supply gap is the percentage of water drawn from groundwater resources by various users. As mentioned earlier, even though IPH operates hand-pumps and motor-pumps in the town, it does not regularly monitor the quantity of groundwater extracted from these sources. Additionally, there are numerous pumping wells operated by individual users in Dharamshala (domestic and non-domestic) which are not officially registered under IPH. As a result, IPH has no record of the exact number of pumps and daily extraction rates of groundwater in the town (Sterkele, et al. 2003).

Yet another factor ignored in the supply gap calculations is the disparity in the distribution of water within the town. First of all, the combined storage capacity is inadequate. Secondly, the municipal storage tanks which temporarily hold water after it has been treated and before it is released via pipes to end-users are not uniformly distributed across the town. As a result, parts of the town may experience greater water shortages than others. All these factors add to the unknowns in estimating the actual gap between supply and demand of water in Dharamshala.

Thus, it can be concluded that the amount of water being made available to users in Dharamshala is different from the quantity that is drawn only from traditional sources, and in turn, the supply gap is likely different from what the surface water calculations indicate. Given the gaps in the information provided by IPH on water supply in the town, and given the limited number of interviewed households in Dharamshala, it is difficult to predict with accuracy the actual difference between supply and demand of water in the town. Therefore, this analysis does not attempt to provide improved estimates of the supply-demand differences, but instead, points out that there are significant imperfections in the records kept by IPH on supply and demand trends. These gaps in information act as barriers to effective adaptation to water scarcity in Dharamshala, and therefore, the final chapter of this thesis presents recommendations on how IPH may improve its data collection records.

Evidence of Climatic Changes and Shrinking Water Supply

The water bodies that provide Dharamshala with its water supply are fed by rainfall as well as snowfall. Climatic changes have impacted the patterns of both these meteorological properties. The changes observed in the behavior of rainfall and snowfall are listed below:

Rainfall

In Dharamshala, during the monsoon season, most of the discharge in surface water bodies is attributable to rainfall. The precise proportion of the water in these sources coming from rainfall is not known. However, studies done on larger rivers in the Himalayas suggest that the contribution of rainwater versus glacial melt-water to river discharge can vary significantly. For example, the Indus River gets approximately 50% of its water from glaciers, whereas the Ganges River gets only 9% of its water from glacial melt, and the rest from rainfall (Eriksson, et al. 2009). In general, during the monsoons, there is ample discharge in the surface-water bodies that supply water to Dharamshala. As a result, during the monsoon season, water scarcity is not perceived to be a salient issue in Dharamshala, even if the quantity of rainfall received by the locality is less than average. According to academicians in Dharamshala, even if this town were to receive only 50% of its average annual rainfall, this amount is still sufficient to meet the annual water demand, provided adequate storage and distribution mechanisms are in place (Dhar 2009). Thus, a crucial factor determining the extent of scarcity faced by Dharamshala is storage capacity (natural storage provided by surface water bodies, which depends on timely rain occurring uniformly throughout the monsoons, and/or man-made storage reservoirs).

Academic research done on Dharamshala indicates that there has been a decreasing trend in the magnitude of rainfall received by Dharamshala since 1990 (Rajwant 2005). These findings seem to be backed by anecdotal evidence at the ground level. For example, local senior residents of Dharamshala stated in their interviews that Dharamshala used to receive much more rainfall in the past than it does now (Dharamshala-Resident 2009). In general, regional climate models predict that as a result of climate change, areas which typically receive abundant rainfall are likely to experience extreme events of highly intense rainfall over a short duration, instead of steady rainfall throughout the monsoon season (IPCC 2007). Thus, in Dharamshala, even if the total quantity of rainfall doesn't decrease by a large percentage, the timing and intensity of the rainfall will largely determine the extent of water scarcity faced by the town in the future.

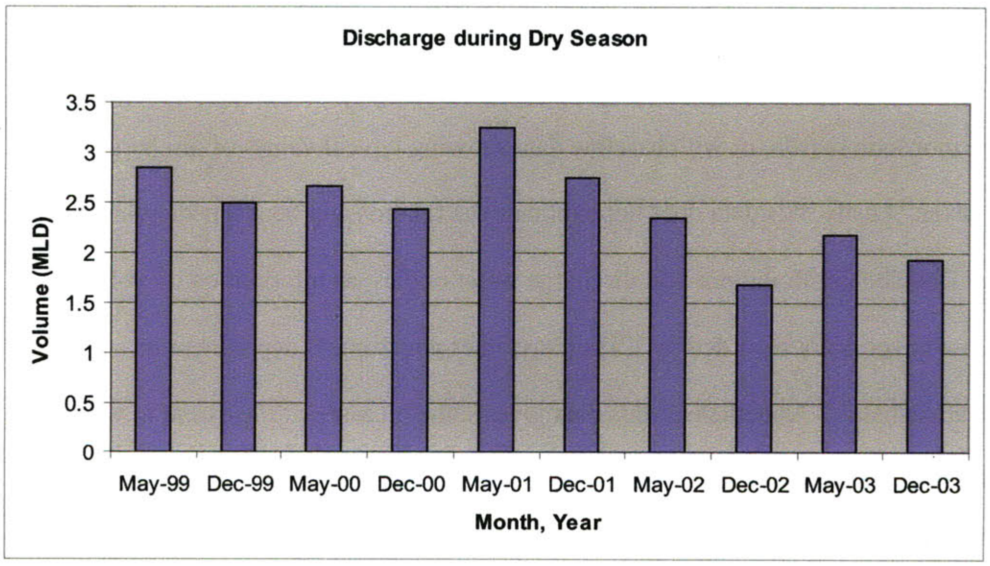
Snowfall

During the dry season (from October through May), the discharge in water bodies (surface and spring) that supply water to Dharamshala is attributable to snow-melt. These sources originate in the Dhauladhar range at an elevation of over 3240 meters (Rajwant 2005). In the last few years, the discharge in these water bodies in the dry summer months of March, April, and May has been reported to be lower than normal by IPH (Department of Irrigation and Public Health 2009). This reduced discharge is a least partially linked to the reduced volume of snow-pack accumulating in the Dhauladhar Mountains which feeds the water bodies that supply water to

Dharamshala. Therefore, if, during the winter, sufficient snow does not accumulate in the Dhauladhar Mountains, and/or if the melting of snow starts earlier in the spring and therefore ends earlier, Dharamshala experiences acute water shortage in the dry summer months of March, April, and May. Once again, it is the natural storage capacity of snow-pack in the Dhauladhar Mountains and the timing of its ablation which influences the availability of water in Dharamshala during the months when there is no other alternative source available such as rainfall.

IPH has documentation of the discharge of all the sources that supplied water to Dharamshala for the period 1999 – 2003, during the months of May and December, as shown in Figure 9 (Department of Irrigation and Public Health 2009).

Figure 9: Discharge of Surface Water Sources in Dharamshala during the Dry Season from 1999 - 2003



Source: Department of Irrigation and Public Health (2009)

As mentioned earlier, the summer season in Dharamshala lasts from March to May and the monsoon season lasts from June to September, followed by winter from October to February. This means that the aforementioned data on discharge of the water sources was taken during dry periods in summer and winter. The discharge in water sources in May is primarily attributable to accumulated snowpack in the Dhauladhar Mountains (peak summer temperatures cause rapid melting of snowpack). The discharge in December is also attributable to snowpack, but the volume of discharge is lower compared to that in May because lower ambient temperatures in winter slow down the rate of melting (Tandon 2009). From Figure 9, it can be seen that from 1999 till 2003, the general trend for discharge in May seems to be decreasing except in the year 2001. The discharge in December shows a similar trend, reaching a minimum value in 2002. This data set has some significant limitations. Firstly, the names and the number of monitored water sources are not specified in the data, and therefore, it is not possible to deduce which sources (and how many) were monitored during this period. Another limitation of this data set is that data on discharge is collected before and after the monsoon season, and not on a continuous basis. Therefore, it is not possible to compare this with discharge levels in the monsoon season, or with baseline data showing typical values of discharge in the sources. Lastly, this data does not explicate the relationship between snow-cover on the Dhauladhar Mountains and discharge water bodies, as information on volume of snow-cover is not recorded by IPH or any other government department in Dharamshala[13]. Nonetheless, this data gives some measure of the extent to which the discharge in the water sources fluctuated during this period.

In addition to this data on dry period discharge, IPH also has records of lean period discharge of the existing and proposed surface water sources from 2002 – 2006 (Department of Irrigation and Public Health 2009). It must be pointed out that the average magnitude of the total discharge in these sources is significantly different

[13] Interviews with a faculty member of Government College, Dharamshala revealed that this academic institution is planning to establish a monitoring system that will collect information on local climate parameters such as snowfall and rainfall pertinent to Dharamshala beginning in 2010. However, there is no long-term data available on climate parameters based on which IPH can check for long-term changes in local climate.

from the data collected for the period 1999 – 2003. One reason for this could be that the data set for the years 2002 – 2006 contains information on existing sources as well as proposed sources (which were ultimately added to existing supply by 2009), whereas the older data-set for the years 1999 - 2003 only contains information on existing sources at that time, the names of which are not specified. The newer data set shows smaller variability in lean period discharge and is presented in Table 8. Nonetheless, the general trend seen in this data is a decrease in discharge. For example, the average discharge from the years 2002 till 2006 is 9.04 MLD, and except for the year 2003, there has been a gradual decrease in the total discharge, with the year 2006 showing the lowest discharge at 8.83 MLD. However, based on this data, it cannot be deduced if this decreasing trend is statistically significant, given the limited sample size.

Table 8: Average Discharge of Water Sources in Dharamshala during the Dry Season from 2002 - 2006

Year	**Bather *Khad* (LPD[1])**	**Churan *Khad* (LPD)**	**Bhagsu Spring (LPD)**	**Dhoop *Nullah* Spring (LPD)**	**Glenmore Spring (LPD)**	**Total Discharge (MLD[2])**
2002	5,315,000	2,895,000	378,000	408,000	115,300	9.11
2003	5,360,000	2,873,400	398,300	418,200	121,350	9.17
2004	5,385,000	2,825,000	338,000	438,000	115,350	9.10
2005	5,350,000	2,800,300	332,200	404,000	119,150	9.01
2006	5,284,000	2,710,100	325,000	400,000	106,670	8.83
					Average	9.04
					Standard Deviation	0.13

[1] LPD = Liters per Day
[2] MLD = Million Liters per Day

Source: Department of Irrigation and Public Health (2009)

Efforts to Address Supply-Demand Gap

In order to close the gap between supply and demand of water in Dharamshala, IPH has adopted a supply augmentation approach in the last ten years. In selecting this approach, IPH has made a number of considerations for alternative sources of water (Tandon 2009). For example, IPH rules out long-range inter-basin water transfer as a viable source of water-supply because it is not cost-effective (Tandon 2009). On the other hand, groundwater resources have been reported to be plentiful in the *Baner* catchment area in which Dharamshala lies. Based on accounts of experts from IPH, Dharamshala has an advantageous geographic location. Dharamshala is in the foothills of the Himalayas, where the environment is still pristine compared to other regions of India. Melt-water from the Dhauladhar Mountains seeps into the ground at the elevation and location where Dharamshala is situated (Dhar 2009). Additionally, according to academicians in Dharamshala, precipitation, infiltration and aquifer rock characteristics are all favorable to recharge of groundwater in the locality (particularly Lower Dharamshala), because it lies in the Piedmont zone (Rajwant 2005). The fluctuations in the levels of the groundwater table in this catchment are conducive to extraction of water in the summer season, during which it is needed the most. Typically, during the winter, the groundwater table drops because cold temperature doesn't allow sufficient snow-melt and therefore there is less groundwater recharge. In the summer, when snow-pack melts, there is increased groundwater recharge and therefore, the groundwater table rises. These factors make groundwater a highly viable resource for Dharamshala in the future (Malhotra 2009).

Having said that, the distribution of groundwater is not uniform across Dharamshala. For example, McLeodganj has poor groundwater extraction potential because it lies in the Lower-Mountainous zone and therefore, groundwater is not a viable alternative for Upper Dharamshala (Sterkele, et al. 2003). Moreover, it is unclear if and how fluctuations in rainfall and snowfall due to climate change will further impact the aforementioned seasonal behavior of Dharamshala's groundwater resources. Nonetheless, IPH does not believe the current rates of groundwater extraction, and those planned for in the near future will lead to lowering of the groundwater table (Malhotra 2009).

In order to tap the region's groundwater resources, IPH has installed a tube-well in a village called Dadi, approximately five kilometers from Dharamshala, which will supply 1 MLD of water to the town[14] (Kapoor 2009). Construction work to add this source to the current network was completed on schedule, and water from the tube-well has been made available since December 2009. More tube-wells are expected to be installed in the future in Dharamshala.

In addition to the tube-well at Dadi, and other proposed tube-wells, IPH has also identified a surface-water body as part of its supply augmentation strategy. This source is a medium-sized stream called Gajeu *Khad* and will supply 2.5 MLD of water to the town. Water from this stream will be made available by March 2010 (Tandon 2009).

Thus, it is evident that so far, IPH has not focused on conservation of water as a strategy for meeting the growing water demand in Dharamshala, and instead, has continued with its tradition of a supply augmentation approach to addressing scarcity. There is no evidence of the involvement of civil society in Dharamshala in water management and this is probably attributable to the centralized regulation of the town's water resources. As a result, the town relies entirely upon measures taken by the government for meeting its requirements. An analysis of the observations made of

[14] The water table in this area is at a depth of 4 meters, which is considered to be favorable. The estimated rate of extraction of groundwater from this tube-well will be 25 liters per second. Water will be extracted with a submersible pump and stored in a reservoir tank. Water from this tank will be distributed by the use of centrifugal pumps to the Dharnu and General Hospital areas of Dharamshala. In Dharnu as well as the Government Hospital area, there are overhead storage tanks which will collect this water. From these overhead tanks, water will be transmitted to individual homes by gravity. The required rate of water transmission in Dharnu is 4 liters per second, and that in the General Hospital area is 8 liters per second. This water is considered to be of very good quality, and will only be chlorinated before it is supplied to homes (Kapoor 2009).

Dharamshala's water resource management is presented in Chapter 7. However, prior to this analysis, the case study of Leh is introduced next, in Chapter 6.

Chapter 6: Water Scarcity in Leh

This chapter draws on the experiences of Leh, a town in the State of Jammu & Kashmir (J&K) that relies on seasonal snow-melt for its water requirements. As in the case of Dharamshala, Leh's water resources have been impacted significantly by climatic changes and urbanization. This chapter follows a structure similar to that of the preceding chapter on Dharamshala (Chapter 5). It presents Leh as a case study for the analysis of possible impacts of climate change and urbanization on its water resources, and the kinds of responses that are emerging in Leh from the government and other sectors to mitigate water scarcity and/or adapt to it.

The first section of this chapter offers background information about the geography, climate, demographics, socio-economics, and political history of Leh, followed by a historical overview of water-use and current institutional management of water resources in this town. Additionally, details about current water sources in Leh, along with data on current and projected demand are described in the second section.

The third section of this chapter describes the changes in the hydrology of the sources of Leh's water supply, which have been attributed to changes in the climatic parameters (e.g. snowfall and temperature) that govern the water availability of Leh. The final section of this chapter presents evidence of responses to water scarcity from the government as well as non-government sectors in Leh.

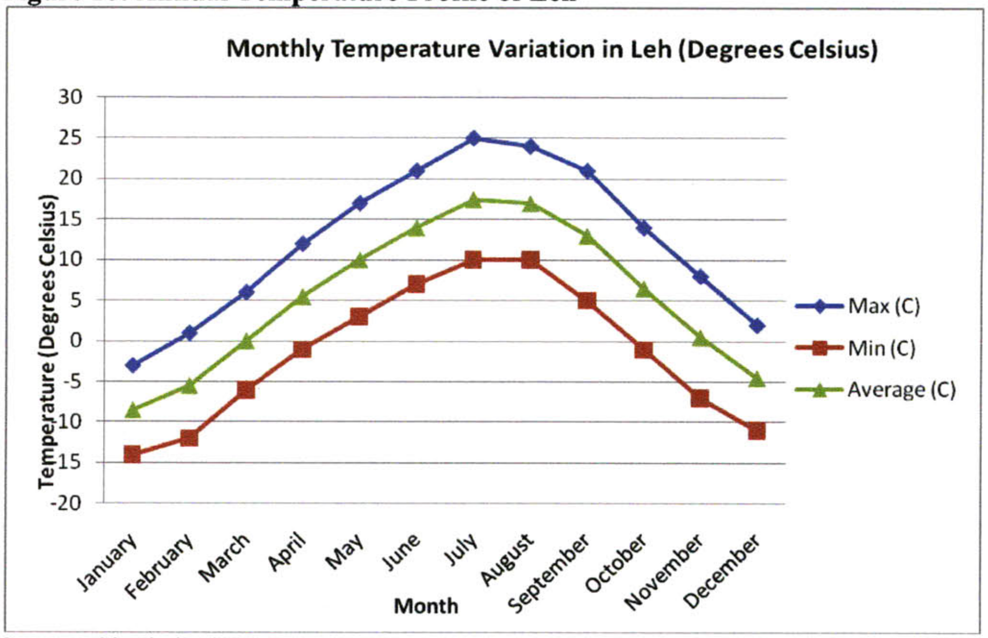
Geography and Climate

Leh is a small town in the north-Indian State of Jammu & Kashmir (J&K). It is located in Leh District, one of the two main districts comprising the Ladakh region (translated as the 'Land of High Passes') of J&K. Leh is located at an altitude of approximately 3,500 meters (National Informatics Center, Leh District, Ladakh n.d.).

It is surrounded by the Karakoram Range in the north, the Kashmir Himalayas in the south, the Tibetan plateau in the east, and the Kashmir valley in the west (Singh 2006).

Leh's climatic characteristics are quite unique from the rest of the Indian subcontinent due to the mountain ranges that surround it. Summer in Leh lasts from May through August, after which the winter sets in and lasts until April. The town receives minimal rainfall (50 – 200 mm/year), mostly during the months of July and August. Therefore, the region of Ladakh is referred to as a cold mountain desert (National Informatics Center, Leh District, Ladakh n.d.). When not covered in snow, the topography in Ladakh consists of rocky, barren, granite mountains, with very little vegetation. The air in Leh is very dry, with relative humidity ranging from 6 – 24% (Tetra Tech 2009). Leh receives high solar radiation due to its high altitude, and consequently, even though temperature in the summer rarely exceeds 28° Celsius, the rarified atmosphere considerably enhances the sun's intensity (Singh 2006). Figure 10 shows Leh's annual temperature profile.

Figure 10: Annual Temperature Profile of Leh



Source: Singh (2006)

Demographics

Currently, Leh has a population of approximately 45,030 in the summer, which shrinks to 31,000 in the winter (Tetra Tech 2009). This seasonal change in the population is partly attributable to the flux of tourists in the summer and their subsequent departure by mid-September. Additionally, some local residents of Leh also choose to migrate to warmer areas during winter, thereby causing the population of Leh to shrink in winter. The total surface area of the city is 19.08 square kilometers (sq. km.) and therefore, the population density in the town of Leh is 1630 - 2370 persons / sq. km. (Tetra Tech 2009), roughly similar to that of Dharamshala (1,136 persons / sq. km.). This density is much higher than the average density of Leh District, which is approximately 6 persons / sq. km. (National Informatics Center, Leh District, Ladakh n.d.). This indicates that the town of Leh exerts more pressure on the natural resources of the region compared to the rest of the district. Additionally, the economy of urban Leh has transitioned from subsistence agriculture and animal husbandry (which is still the primary means of livelihood for the rest of Ladakh) to a non-agriculture-based service economy (H. Singh).

Leh has a predominantly Buddhist population, followed by Muslim and Hindu minorities. Approximately 82% of the population is Buddhist, 15% is Muslim, and 3% is Hindu. Table 9 shows past trends in population growth as well as future projections for Leh for the next 30 years. From this table, it is evident that the population of Leh rose significantly in the 1990s and is expected to increase by 100% of the 2009 population by the year 2040 (Tetra Tech 2009).

Table 9: Population Projections for Leh

Year	Summer Population	Winter Population	Average Population
1961	-	-	3,720
1971	-	-	5,519
1981	-	-	8,718
1991	-	-	9,897
2001	-	-	28,639
2009	45,030	31,000	38,015
2010	46,145	35,496	40,821
2025	69,462	49,994	59,728
2040	94,365	67,888	81,127

Source: Tetra Tech (2009)

Socio-economic Characteristics

The indicators of socio-economic development in Leh District and J&K are not as strong as those of Kangra District or Himachal Pradesh. For example, the literacy rate in Leh District according to the 2001 census was 62.24% (slightly lower than the national average of 65.38%) (National Informatics Center, Leh District, Ladakh n.d.). The per capita income of Leh District could not be found, but if J&K's average per capita income of Rs. 12,399 ($278) is used as an indicator, it is clear this income is below the national average of Rs.16,707 ($375) (Guruswamy 2004). Leh's economy has traditionally featured subsistence agriculture, and according to the 1981 census, 66.32% of the population was engaged in agriculture-related occupations

(National Informatics Center, Leh District, Ladakh n.d.). However, with the expansion of the tourism industry in urban Leh, the town is experiencing major socio-economic changes and tourism is currently the backbone of urban Leh's economy (Tetra Tech 2009).

Government and Administration

The town of Leh is the headquarters of Leh District, and the urban center of the region of Ladakh. Ladakh has undergone several political reforms since the 1940s. After India gained independence in 1947, Ladakh became an integral part of J&K. Ladakh (which used to be one district) was perceived as an area crucial to India's national security, and as a land of immense cultural diversity. However, it was one of the least economically developed regions of India. All of these factors played a significant role in shaping the policies that govern the region today (Aggarwal 2004). Until 1980, Ladakh district was governed by a Deputy Commissioner, an officer of the Indian Administrative Service of the Government of India. In the early 1980s, Ladakh District was split into two new districts, Leh and Kargil, and consequently, each of these districts was governed by its own Deputy Commissioner (Jina 2002). The following years were marked by political turmoil in J&K, which provided Ladakhi interest groups with an opportunity to further their political agenda, and have their demands met.

In 1989, the Ladakh Buddhist Association, a politico-religious organization in Ladakh demanded that their community be recognized as Scheduled Tribes[15]. This demand was granted in 1989, following which there was more agitation from the Ladakh Buddhist Association about the J&K government's unfavorable attitude towards Ladakhis (Jina 2002). These protests intensified after a state of emergency

[15] Scheduled Tribes are one of many population groupings explicitly recognized by the Indian Constitution as those that are entitled to specific benefits and resources in order to enable their social inclusion into mainstream Indian society.

was declared in J&K in 1990 and the ruling State Government was dissolved, thus bringing J&K directly under the Governor's administration (Aggarwal 2004). The Ladakh Buddhist Association joined forces with the Ladakh Muslim Association and demanded that the Ladakh region be granted political autonomy. Eventually, in 1995, this demand was granted by Mr. Shankar Dayal Sharma, the President of India at the time, when he approved the Ladakh Autonomous Hill Development Council Act (Aggarwal 2004). This act prescribed separate councils for each of the two districts in Ladakh (Leh and Kargil) and an inter-district advisory council for the entire Ladakh region, which the J&K State Government could partly constitute in consultation with the councils of Leh and Kargil (Jina 2002). The council in Leh came to be known as the Leh Autonomous Hill Development Council (LAHDC). Thus, the region of Ladakh was allotted substantial executive & legislative powers and functions within the J&K framework, and in several ways, benefited from this autonomy (Aggarwal 2004). For example, employment rates in Leh were improved, and inefficient subsidies were removed, encouraging Ladakhis to play a more active role in their economic development. Additionally, LAHDC also exhibited greater accountability and transparency in their operations compared to the J&K government (Aggarwal 2004).

However, in subsequent years, the autonomy of LAHDC was threatened by higher political leadership. Additionally, the demands of interest groups were kept in check. For example, the Ladakh Buddhist Association, despite its perseverance, was denied its demands to grant Ladakh the status of a Union Territory[16], particularly after Parliamentary and State Legislative elections resumed in J&K in 1996 (Aggarwal 2004). This turbulent political history of Ladakh in the context of J&K has often

[16] Union Territories are sub-national administrative divisions of India that are directly governed by the federal government and not by the state government.

created conflict between the local government body (LAHDC) and the State Government, particularly with regard to the management of LAHDC's budget. Thus, LAHDC, to this day, governs the town of Leh amidst larger debates about its identity, as well as that of J&K in the Indian political system.

Status of Water Use in Leh

As in the case of Dharamshala, the management structure of water resources and the types of water-use in the town of Leh have changed considerably in the last five decades. Even though piped water supply is becoming increasingly available, not all parts of the town have access to it (Akhtar 2010). By the year 2001-02, a total of 606 water connections had been installed in Leh, out of which 297 (49%) were private and 306 (51%) were public stand-posts (PSPs). By the year 2009, the number of PSPs had risen to 389, out of which 150 are operational in winter. Based on past trends, it is assumed that the number of private connections has increased by the same magnitude, and presently, approximately 375 private connections exist in Leh. Of these private connections, 274 (73%) are owned by commercial users (i.e. hotels and guest-houses) and therefore, it is evident that only a quarter of private connections are owned by residential users (Akhtar 2010). This indicates that most households in Leh rely upon PSPs for their daily water needs.

Prior to the introduction of piped water, people in Leh used to fetch water from springs (locally known as *chumiks*) and streams (Norphel 2009). Historically, the inhabitants of Leh have displayed a strong tradition of frugality in their use of their water resources. This conscientiousness has been due to the limited supply of water in this cold desert region. In order to conserve water, people would not bathe or wash clothes on a daily basis (Norphel 2009). Additionally, traditional Ladakhi toilets (dry composting toilets) were the norm in the entire town, regardless of class or location. The weather conditions in Leh were (and still are) perfectly suited to the efficient operation of dry composting toilets. However, with the availability of piped water, and the expansion of the tourism industry, a water-intensive sewage system with septic tanks, or in some cases, outfalls discharging wastewater into streams, is becoming increasingly prevalent in the town, exerting a greater pressure on Leh's scarce water resources (Hasnain 2009). A survey of approximately 100 households conducted in 2009 by a local environmental community organization called the Ladakh Ecological Development Group (LEDeG) as part of an investigation on household water consumption reveals that 23.8% of surveyed households possessed a flush toilet[17] (Akhtar 2010). Among those interviewed, 50% of the households which did not currently posses a flush toilet desired one, indicating a demand for water-intensive sanitation. Other reasons why water consumption has increased in Leh include an overall increase in sense of hygiene (e.g. washing dishes and clothes more often), or increased use of modern facilities which consume more water (e.g. washing machines) (Akhtar 2010).

Institutional Management of Water

The LAHDC consists of various divisions, of which the Public Health and Engineering Division (PHE) is in charge of water management (National Informatics Center, Leh District, Ladakh n.d.). This division is categorized as an 'Essential Department', and was created in 1984, prior to which the Roads and Buildings (R&B) Division was responsible for Leh's water management. The growing need for a specialized division for water management in the last 25 years is evidenced by this very important change in the departmental structure of LAHDC. PHE has three sub-

[17] It should be pointed out, however, that these toilets are not operational during the winter, and 25% of households that had these toilets only kept them for guests, while using traditional Ladakhi toilets for their own needs (Akhtar 2010).

divisions, of which the Leh sub-division is in charge of water supply in the town of Leh.

The primary objective of this sub-division is to supply potable water to the residents of Leh (National Informatics Center, Leh District, Ladakh n.d.). Additionally, PHE is also responsible for sewage services, but assigns a higher priority to water supply. Unlike Dharamshala, it seems that Leh's water management is not regulated by a top-down, State-level water policy, and in fact, is highly decentralized. PHE's operations are guided by its primary goal of securing water for the town of Leh, and PHE is accountable to LAHDC.

As far as operational management is concerned, the hierarchy of administration at PHE is similar to that seen in Dharamshala. At the top of the hierarchy is the district superintending engineer, who reports to the Governor of J&K, followed by an executive engineer responsible for each town, who supervises field engineers in charge of daily water services within the town. As in the case of Dharamshala, field engineers are most familiar with the daily operations of PHE, but are so overwhelmed with responsibilities related to fixing malfunctions in the system, that they find it difficult to devote time to proactive planning for organizational improvements. Additionally, similar to Dharamshala, the structure of PHE also shows evidence of technocratic management in the way water scarcity is defined and addressed. This form of management is discussed in greater depth in Chapter 7.

The water tariffs in Leh follow a fixed-tariff pricing structure. PHE currently charges Rs. 360/month/connection ($8.09) to domestic users with private connections and Rs. 1000/month/connection ($22.46) to commercial users (Kaul 2009). Water made available through PSPs is not priced. In areas where piped water supply cannot be made available, water tankers are provided by PHE (See Figure 11), which supply water at the rate of Rs. 500 ($11.23) per 1000 liters.

Figure 11: Water Tankers provided by PHE to transport Water

Additionally, the absence of piped water connections in many parts of the town has given rise to an informal economy of water transport and sale. Water-sellers in Leh collect water from streams or springs flowing through the town in 200 liter barrels and sell it door-to-door in a hand trolley (See Figure 12). Water procured in this manner costs Rs. 30 ($0.67) per 200 liter barrel.

Figure 12: Barrels used to transport Water in Leh's Informal Water Delivery Economy

In light of the water pricing structure prevalent in Leh, it is important to analyze the nature of subsidization of water resources in this town. The monthly tariffs for private water connections are significantly higher than those applied in Dharamshala under the fixed-tariff pricing structure which was enforced in Dharamshala prior to 2005 (See Table 3 in section on "Institutional Structure of Water Management" in Chapter 5). Additionally, the structure of subsidies granted to various sectors in Leh is different from that of Dharamshala.

It is estimated that the average use of water per household in Leh is 84 LPD in the summer and 56 LPD during winter (Akhtar 2010). Based on household surveys conducted by LEDeG, the average household size in Leh is 4 members. This suggests that the average per capita daily water consumption in the domestic sector in Leh is 20 liters in the summer and 14 liters in the winter (Akhtar 2010). However, households with private connections likely consume much more than those that rely on PSPs, tankers, or barrels for water (Cairncross, et al. 1993). Under this same logic of greater supply driving greater demand, the water consumption habits of tourists are found to be quite different from those of local residents (Akhtar 2010). Surveys show that on average, tourists use water-based flush toilets and consume 81 liters of water per day if they use shower-heads for baths, and 55 liters per day if they take bucket baths. It is estimated that nearly 50% of large hotels in Leh have water-based flush toilets. Approximately 93% of guest-houses (homes that offer lodging) offer the option of Ladakhi dry toilets, but surveys show that these toilets are only used by the house-owners and not by guests. Overall, less than 2% of the tourist population is believed to be comfortable using dry Ladakhi toilets (Akhtar 2010).

Given these disparities in the volume of water consumed by different populations in Leh, an estimation of the extent of subsidization of water in Leh is more complicated. Calculations of subsidization require estimates on costs of water production, and the following assumptions are made about the cost of water production in Leh: Since most of piped water is not treated centrally nor distributed through centralized water systems, the cost of treatment of water (if any) is incurred at the point of use by consumers and not by PHE. However, lifting of the water from the Indus basin, or extraction of groundwater likely constitutes a significant portion of the total water production cost in Leh. Given the lack of data on water production costs specific to Leh, an average cost of water production of Rs. 15 per KL ($0.34 per KL) is assumed based on national averages for urban areas (Raghupati and Foster 2002), and using this estimate, the monthly cost of water services[18] to various households and sectors is presented below in Table 10.

Table 10: Daily Water Consumption by Sector and Cost of Water Services

Users	**Daily Consumption per Connection (LPD[1])**	**Estimated Monthly Cost of Water Services (Rs.[2])**
Guest-houses	1,976	Rs. 889.20 ($19.97)
Hotels	3,360	Rs. 1,512.00 ($33.96)
Households (Summer)	84	Rs. 37.64 ($0.85)
Households (Winter)	56	Rs. 25.20 ($0.57)
[1] LPD = Liters per Day [2] Rs. = Rupees		

Source: Daily consumption rates are calculated based on calculations done by Akhtar (2010). Monthly costs are estimated based on assumptions made about the cost of water production in Leh.

From Table 10, it is clear, that commercial users (hotels and guest-houses) are the largest consumers of water in Leh. If hotels pay Rs. 1000/month for their water connection, and the cost of the average amount of water consumed by the hotels is Rs. 1,512, it implies that water supplied to the commercial sector is subsidized by approximately 34%. At the individual level, residents consume significantly lower amounts of water compared to tourists, as shown in Table 11.

[18] Estimated Monthly Cost of Water Services = Daily Consumption per Connection (LPD) x 30 days/month x 1000 Liters/Kilo-Liter x Rs. 15/KL

Table 11: Water Consumption by Individuals and Cost of Water Services

Users	Daily Per Capita Consumption (LPD[1])	Estimated Monthly Cost of Water Services (Rs. [2])
Residents (Winter)	14	Rs. 6.30 ($0.14)
Residents (Summer)	21	Rs. 9.41 ($0.21)
Tourists (with access to showers)	81	Rs. 36.45 ($0.82)
Tourists (with access to bucket baths)	55	Rs. 24.75 ($0.56)
[1] LPD = Liters per Day [2] Rs. = Rupees		

Source: Akhtar (2010)

Assuming that the cost of water production estimated in this analysis is close to its actual value, it appears that commercial users are reaping the greatest benefits of subsidized water. Local residents who do not have access to private water connections do not pay the monthly fee of Rs. 360 ($8.09). But clearly, their use of water is minimal as they have to manage with the amount of water they can acquire from PSPs. In fact, if they acquire water from tanks or barrels, they a premium price for water. On the other hand, owners of guest-houses (who offer lodging services in their homes) have been known to register their business under the domestic user category and are therefore charged only Rs. 360 per month for water connection and supply, when it is obvious that their use of water is significantly higher than regular home-owners or the average local population of Leh. Additionally, it is estimated by PHE that approximately 20-30% of water supplied to the town of Leh is used for urban agricultural purposes (Kaul 2009). It is reasonable to assume that this use of potable water for agricultural purposes is practiced by users with private water connections. Thus, these are some examples of how low values of fixed tariffs for the domestic sector are being abused by the commercial sector.

Additionally, pro-tourism policies in Leh have been reinforcing unregulated use of water by the commercial sector since the mid 1990s (Akhtar 2010). According to studies conducted by LEDeG, owners of registered hotels and guest-houses can apply for financial assistance during the construction or expansion of their business. The local government is known to subsidize up to 35% of the construction costs of tourism development projects, with provisions for additional assistance for large-scale projects (Akhtar 2010). The number of hotels in Leh has increased from 119 in the year 1999 to 274 in 2009 (an increase of 130%). It is in this manner, that the Leh Development Authority (an agency established in 2005 to promote development projects in Leh district) is indirectly subsidizing greater use of water by larger hotels (Akhtar 2010). The fixed-tariff pricing structure is unable to check the consumption of water by large hotels, and modern amenities like showers or water-intensive toilets attract more tourists, thereby creating incentives to consume more water under this pricing model (Akhtar 2010). Moreover, hotels have the resources to install their own private pumping wells and obtain access to 24-hour water supply, and therefore, in cases where the municipal supply has been unable to meet their water demands, hotels have invested in tapping groundwater resources which are not priced nor regulated by PHE (Ete 2009).

Current Supply Sources and Distribution of Water in Leh

Historically, Leh has relied on streams or springs that emanate naturally from the sub-surface for its water requirements. These sources originate from the snow-melt of the Khardungla Glacier (Norphel 2009). However, in the past few years, some of these traditional sources (particularly streams) have become unviable, and this is linked to the recession of snow-pack in the Khardungla region[19]. Simultaneously, the demand for water has been increasing in Leh as a result of rapid urbanization, economic development, and population growth (Deen 2009). To bridge the gap between supply and demand, PHE as well as private users (domestic and commercial) have started tapping groundwater sources in the last decade. As a result of the availability of bore-well technology, hotels, guest-houses as well as some households have installed private borehole wells to meet their water demand. It is approximated that 42% of tourist accommodations use private pumping wells in Leh (Akhtar 2010). A limiting factor for the installation of pumping wells is the cost and ease of access to the intended location of the well. The number of wells installed in Leh has increased after 2002, when there was a major improvement in the transportation infrastructure of Leh, which, in turn, improved accessibility (Akhtar 2010).

Thus, overall, the current supply system uses natural springs as well as extracted groundwater from pumping wells as sources of water (Tetra Tech 2009). In terms of municipal supply, Leh currently has 12 independent water-supply schemes. Under these schemes, there are 4 natural springs and 11 tube-wells that supply water to the town of Leh, bringing the total current supply to 3.52 MLD. The geographic distribution of the tube wells spans across the entire town all the way to the bank of the Indus River. However, the extent of total discharge in surface sources and the extent of groundwater resources available to Leh have not been quantified. Therefore, it is not possible to categorize the extent of water stress in Leh according to the index developed by Falkenmark and Lindh (1976).

[19] There are no monitoring systems in Leh that collect quantitative data on changes in the average volume of snow-pack on Khardungla Glacier, and therefore, anecdotal information and local informal knowledge is relied upon to get an idea of climatic changes affecting Leh's water sources.

Another example of the gaps in PHE's data is the information available on water treatment. There isn't sufficient data to show what percentage of water is treated before consumption. However, it is generally believed that water sources in Leh are pristine, and not vulnerable to serious contamination. For example, hotels extracting groundwater by borehole wells do not treat it at all prior to distribution (Hotel-owner 2009). Water supplied to the army in Leh is chlorinated, but for the most part, water treatment services are not provided by PHE (Akhtar 2010). Table 12 lists the various sources of municipal supply in Leh. This list does not include private pumping wells that may be installed by individual consumers.

Table 12: Sources of Municipal Water Supply in Leh

Source	**Capacity (MLD[1])**
Gaylung Spring	0.47
T Trench Spring	0.15
Sakara Spring	0.45
JumaBagh Spring	0.09
Jumabagh Tube well	0.24
Skalzangling Tube well	0.12
Sankar Tube well	0.17
TW – 1	0.3
TW – 2	0.3
TW – 4	0
Khakshal Tube well	0.3
Tukcha Tube well	0.24
TW – 3	0.09
Badami Bagh Tube well	0.12
Morse Tube well	0.24
Lari Mo Tube well	0.24
Total	**3.52**
[1]MLD = Million Liters per Day	

Source: Tetra Tech (2009)

For public connections, water is transmitted via pipes to public stand-posts (PSPs). PSPs are in the form of taps or hand-pumps. The daily tap-water supply is limited to approximately two-three hours, typically in the morning. Hand-pumps, in theory, can yield water round the clock but it does not seem that these resources are over-exploited, since the pumps are in public locations and not convenient to access multiple times during the day, or often in a state of disrepair. According to PHE records, there are 389 PSPs in Leh as of 2009, of which 150 run during winter (Akhtar 2010). Residents who do not have access to private household pipe connections obtain water from PSPs, or in some cases, directly from natural springs, and carry it home and store it in buckets (Leh-Resident 2009). Users who have private household connections from the municipal supply typically receive water for one-three hours a day via pipes at different times of the day. This water is then stored in overhead household storage tanks owned by the individual users, from which water is distributed throughout the building (homes, guest-houses, or hotels) (Leh-Resident 2009). Thus, PHE employs a form of rationing (i.e. limiting supply to a few hours every day) that is commonly practiced in most parts of India, as limited resources prevent municipalities from offering a continuous water supply throughout the day. In the last few years, the duration of daily water supply for both private as well as public connections is reported to have decreased, implying that the PHE has probably been modifying the amount of water provided to the town based on the volume of discharge available in its supply sources[20] (Leh-Resident 2009).

Storage Reservoirs

There are nine service reservoirs with a total capacity of 3.6 million liters in Leh (Tetra Tech 2009). The total storage capacity of these reservoirs is barely sufficient to hold a day's worth of Leh's water supply, which is 3.52 million liters. Moreover, the reservoirs are not evenly distributed across the town (Kaul 2009), and therefore, there are some parts of the town that do not have adequate storage capacity.

[20] This observation is based on informal interviews of residents conducted by the author in Leh.

Thus, similar to Dharamshala, Leh is unable to store more than a day's water supply and has no storage capacity to guard the town against unforeseen circumstances.

Current and Future Demand for Water in Leh

In light of the Leh's urbanization and population growth, studies have been commissioned by PHE to determine the extent of current and projected demand for water in Leh (Dorjay 2009). Table 13 shows the increase in demand for water up to the year 2040 based on summer and winter populations. From this data, it is evident that the demand for water in the year 2040 will be twice the current demand in 2010.

Table 13: Projected Demand for Water in Leh based on Summer and Winter Populations

Year	Summer Population	Summer Demand (MLD[1])	Winter Population	Winter Demand (MLD[1])
2010	46,145	7.16	35,496	5.51
2025	69,462	10.78	49,994	7.76
2040	94,365	14.6	67,888	10.54
[1]MLD = Million Liters per Day				

Source: Tetra Tech (2009)

Gaps between Supply and Demand

The demand for water in Leh is estimated on the basis of a minimum acceptable daily consumption rate of 135 liters/capita + 15% loss of 'unaccounted for' water. This consumption rate is prescribed by the Central Public Health & Environmental Engineering Organization under the Ministry of Urban Development, Government of India for cities provided with piped water supply where a sewerage system exists or is being contemplated (Tetra Tech 2009). In reality, however, particularly in the domestic sector, the residents of Leh have been conditioned to restrict their water use to as low as 14-20 LPCD (Akhtar 2010). Indeed, some residents in lower income areas of Leh have limited their use of water to only drinking and cooking. They bathe and wash their clothes every few days in nearby streams (Norphel 2009).

Therefore, it is debatable if generally prescribed rates of allowable consumption of water are applicable in arid localities such as Leh. However, for the purpose of estimating the gap in supply and demand of water in this analysis, the guideline of 135 LPCD is used in calculating demand, implying that the daily water demand of the current population in Leh is between 5.51 and 7.16 MLD[21].

The current supply is at approximately 3.52 MLD (see Table 12). Therefore, the gap in supply and demand is 1.97 – 3.62 MLD, and will only increase in the next three decades. It should be noted that this calculated gap between supply and demand is only an approximation, and assumes that the sources of water are operating at maximum capacity. However, in reality, out of Leh's 12 water supply schemes, some are often not operational in the winter, and some have shown reduced discharge (Kaul 2009). Therefore, piped water connections are frequently interrupted. The gap between supply and demand is further widened as a result of the quantity of water lost due to leakages. The water supply infrastructure in Leh has not been renovated since the 1980s (Tetra Tech 2009). Freezing of the pipe network leads to frequent bursting of pipes in the winter. In the past, expansion of the network has consisted mostly of non-insulated galvanized iron or plastic piping, and has been slow and unorganized. Lastly, negligence towards maintenance of PSPs and a lack of well-defined procedures for water supply via portable tanks also lead to water losses (Akhtar 2010). For example, water has often been found running from PSPs during times when no one is using it. Similarly, water being transferred from tube-wells to tanks is often splashed carelessly because the inlet of the tank is not aligned with the outlet of the tube-well (Akhtar 2010). All these factors are believed to contribute significantly to water losses, but the exact quantity of water that is unaccounted for has not been

[21] This daily demand has been calculated by multiplying the summer and winter populations of Leh by the guideline of 135 LPCD.

determined. Lastly, the extent to which individual pumping wells installed in Leh by various users (commercial or residential) are affecting the supply-demand gap is unclear, as the extraction of water from these sources is not documented. On account of these factors, it can be concluded that the gap in the supply and demand of water in Leh is likely different than what the data suggests. As pointed out in Chapter 5, this thesis does not attempt to present an accurate estimate of the gap between supply and demand, rather the goal of this thesis is to point out the closing the gaps in this kind of information that can help the town of Leh adapt better to water scarcity.

Evidence of Climatic Changes and Shrinking Water Supply

Given that Leh receives minimal rainfall, the town has relied almost entirely on natural spring sources that carry snow-melt from the Khardungla Glacier, and more recently on groundwater to meet its water requirements. The Khardungla Glacier used to be a permanent glacier approximately 4-5 decades ago (Deen 2009). Since then, anecdotal evidence shows that this glacier has retreated, and essentially, the distance between the snout of the glacier and the town of Leh has increased. Typically, glaciers melt faster at lower altitudes, but if they recede to higher altitudes, they take longer to melt. It is believed that this has led to lower discharge of water in springs and streams that are fed by the Khardungla Glacier (Norphel 2009). Changes in temperature and local precipitation have also been perceived by residents of Leh. Locals recall that until approximately 15-20 years ago, Leh used to experience a 'white winter' and would be covered with up to 6 inches of snow throughout the winter (Deen 2009). Now, winters have become warmer, and snow does not accumulate for long within the town. It is estimated that Leh has experienced a temperature increase of approximately 1 Celsius on average (Stobdan 2009).

An accurate approximation of the reduction in discharge of the water supply sources of Leh is not available. But it is estimated by engineers at PHE that the Juma Bagh spring and the T-Trench spring are serving at 25% and 50% capacity respectively, and the Shari spring has been reported to be 99% dry (Kaul 2009). Additionally, existing tube-wells located in the Khakshal, Changspa, Skampari, Mane-Tselding and Badami Bagh neighborhoods of Leh have shown a decrease in discharge as a result of a decline in the water table (Kaul 2009). This decline has not been quantified, but is said to have impacted the above-mentioned neighborhoods substantially. The commercial sector has also perceived a decrease in the viability of water supply sources in Leh. For example, hotel owners have complained of pumping wells that had gone dry last year during the tourist season (Akhtar 2010). This could indicate that the rate of extraction of water from these pumping wells is not sustainable and/or that the water table has been declining due to insufficient recharge from snow.

Efforts to Address Supply-Demand Gap

PHE's strategy in securing a reliable water supply to Leh has almost exclusively involved source augmentation. Prior to 1996, the primary sources of water in Leh were springs in the Juma Bagh neighborhood (National Informatics Center, Leh District, Ladakh n.d.). The water supply was enhanced by the installation of 3 tube-wells with assistance from the Central Groundwater Commission. It was later discovered that one of these wells was not viable. Additionally, the service reservoirs that collected water from these tube-wells were at a higher elevation, which necessitated the lifting of water, for which a source of power was not guaranteed. As a result, the tube-wells and service reservoirs became defunct. Subsequently, the existing supply was augmented by drawing water from a spring in the Gaylung neighborhood of Leh, and by installing a groundwater well in the T-Trench neighborhood (National Informatics Center, Leh District, Ladakh n.d.).

In 1996, yet another multi-stage augmentation program was initiated. It involved the installation of additional tube-wells in three areas near Leh along with arrangements to lift water from these wells and transport it to Leh. This scheme was completed in 2000 and reportedly provides 100,000 gallons of Leh's total water supply. In the second stage of this scheme, two additional wells were installed in two other areas of Leh along with service reservoirs.

Interestingly, the designated source of power required to lift water from these wells and transport it to the town was hydropower. However, the hydropower potential of surface water sources in this region has proven to be erratic, and subsequently, diesel was designated as the new source of power for this program (National Informatics Center, Leh District, Ladakh n.d.).

In 2002-03, yet another series of augmentations took place in Leh. This time, however, in addition to the installation of new tube-wells and service reservoirs, the withdrawal of water from existing sources was also increased, and some improvements were made in the water conveyance network. More water was drawn from the Leh *Nullah* (local word for stream) and Gaylung spring, and a formerly defunct tube-well was reactivated. The Leh *Nullah* also supplied irrigation water to nearby villages. To compensate for the increased withdrawal from Leh *Nullah*, two tube-wells were added to meet irrigation requirements which were earlier met by Leh *Nullah* (National Informatics Center, Leh District, Ladakh n.d.). This improvement in infrastructure and networks was intended to reduce expenditure, and this goal was achieved to some extent. However, based on the numerous problems that PHE has faced with their expansion programs, it seems there was a lack of investment in systematic evaluation of the long-term viability of past schemes.

This reactive approach to water-supply planning seems to have recently changed. The projected increases in the demand for potable water in Leh, and the observed decreases in supply have prompted LAHDC to seek a long-term plan for the future of Leh's water system. In 2008, LAHDC hired a private consulting firm, Tetra Tech, to conduct a study on the augmentation and reorganization of water supply in Leh. In commissioning this study, the objective of LAHDC was to "ensure a sustainable and equitable water supply to Leh" (Tetra Tech 2009). The most significant finding of this study is Tetra Tech's estimation of groundwater resources in the Leh region, which forms the premise for most of the recommendations made in the proposal.

According to the report, groundwater resources in the Leh region are abundant. For example, the report states that the southern part of Leh (near the Indus River) is said to have "very good groundwater potential". The northern and central areas of Leh have "good groundwater potential". The area of Gymsta and Mane-Tselding have "moderately good potential" and the extreme eastern and western areas have "poor groundwater potential" (Tetra Tech 2009). In light of these findings, the principal recommendations of the report include measures to install an infiltration well at the bank of the Indus River, the water from which would be designated for the upper reaches of Leh up to T-Trench Service Reservoir. Water from this infiltration well would be delivered to upper Leh via the installation of four new lifting stations at various locations along with the renovation of two existing lifting stations. Aside from short-term measures, the report also makes recommendations on long-term augmentation of supply sources, such as the installation of 10 new tube-wells by the year 2040 at various locations in Leh (Tetra Tech 2009).

In addition to specific recommendations for identification of additional water sources, the report makes some recommendations for the overall improvement of the services provided by PHE. For example, the report calls for the installation of five new service reservoirs in areas which currently do not have reservoirs, as a means of increasing the water storage capacity of the town. Secondly, there is also a recommendation to expand the distribution network and improve connectivity by adding piping between new water sources and reservoirs, as well as between reservoirs and the point of use (Tetra Tech 2009).

Thirdly, there are specific suggestions to enable conservation of water, such as the re-laying of the entire distribution network using more durable pipe material in order to prevent water losses from leakages, or taking measures for preventing freezing of water at various points in the distribution system (i.e. at lifting stations, reservoirs, or pipes). Lastly, the report calls for measures to strengthen the internal capacity of PHE via training of staff at various levels, as well as measures to facilitate public engagement via the adoption of Information, Education, and Communication (IEC) principles (Tetra Tech 2009).

Thus, it may be summarized that despite the inclusion of some recommendations that focus on water conservation or organizational changes, the emphasis of the report is predominantly on supply augmentation, particularly through the exploitation of groundwater resources. Assuming that PHE follows the recommendations made in this report, it can be said that there won't be a significant departure in PHE's strategies to address water scarcity from those employed by this agency in previous years.

Interestingly, the government is not the only sector that has been involved in the management of water resources in the region of Ladakh. In addition to governmental efforts to address water issues in Ladakh, the magnitude of the water crisis in this region has mobilized action from the non-governmental sector. This evidence of scattered adaptation measures at the project level, spearheaded by community organizations, is presented in the following sections.

Other Efforts on Adaptive Management of Water Scarcity in Leh:

The civic sector has recognized the need to address water shortage in Leh for the past two decades. However, planning for bottom-up, project-based adaptation to water scarcity in Leh is in its formative stage, and is primarily concentrated in rural parts of Leh District as opposed to urban Leh. The following non-government organizations have shown initiative in responding to changes in the water availability of Leh district:

LEDeG: Ladakh Ecological Development Group:

LEDeG is a non-profit organization that focuses on ecologically and socially sustainable development in harmony with traditional Ladakhi culture. LEDeG was founded in 1983, and historically, this organization has been involved in environmental education, dissemination of renewable energy technologies, sustainable agriculture projects, capacity building of micro-enterprises, and watershed development (LEDeG n.d.). Traditionally, the focus of LEDeG's activities has been on rural development. However, LEDeG has recently acknowledged the need for intervention in the water management of urban Leh (Hasnain 2009).

Consequently, in 2009, LEDeG initiated a program for a *Comprehensive Approach to Groundwater Management* in Leh. The goal of the program is to create a knowledge-based approach to "sustainable use and management of water in the urban region of Leh" (LEDeG 2009). This program has 3 components, the first of which involves creating a scientific knowledge base that will guide future action. The database would contain information on demand and supply trends, the extent of groundwater resources in the Leh region, and the extent of the use of pumping wells by public authorities as well as private users. The second component of the program is initiating a pilot project in order to explore measures to conserve water by facilitating groundwater recharge and deploying sustainable sanitation technologies. The final component is to conduct advocacy with the government and the community to induce behavioral changes and create a favorable environment for the introduction of regulation in water use.

This program is a response to LEDeG's perceived lack of information available on groundwater and surface water resources available to Leh. According to LEDeG, there is little reliable information on the extent of water resources in Leh, based on which organizations like LEDeG could make policy recommendations. LEDeG also contends that there is no systematic evaluation protocol followed when new water resources are explored. Specifically, there is no systematic collection of information on groundwater resource boundaries, water-table levels and aquifer quality when new water sources are explored (Ete 2009).

The first draft of the objectives of this study was released in August 2009 internally, among the staff of LEDeG in August 2009. It is clear, that during the scoping of this proposed study, LEDeG was not privy to the details of the report prepared by Tetra Tech in 2009, which contains at least some information on the extent of groundwater resources available to Leh. Given that Tetra Tech's proposal has not been made available to the public, this presents a risk of duplication of plans to address water scarcity in Leh. Thus, there is an urgent need for open communication between the local government and non-government organizations in Leh.

Leh Nutrition Project (LNP)

LNP is a non-profit organization that was founded in 1978 and has been engaged primarily in rural development in Leh District. Its focal areas are primary health care, education, agriculture, handicrafts, and nature conservation (Reach Ladakh 2009). LNP has recently been trying to shift its mission from service provision and project implementation to capacity-building and enabling. In the area of water conservation, LNP has been involved in various watershed projects in 25 villages in Leh District (Norphel 2009).

LNP's projects in watershed management have primarily been spearheaded by one individual, Mr. Chhewang Norphel. Mr. Norphel, a civil engineer by training, is currently the director of LNP's watershed program. In his work, Mr. Norphel draws from his personal experience as a Leh resident and his professional expertise in locally adapted technologies such as artificial glaciers and ponds.

According to Mr. Norphel and his team, the Khardungla Glacier, which used to be perennial, has shown fluctuations in its accumulation of snow in the last four decades (Norphel 2009). In the region of Ladakh, 80% of the population relies on agriculture for their livelihood. Thus, in essence, the population depends on water resources from the Khardungla snow-pack, and it is critical that farmers have timely access to water prior to sowing (Norphel 2009). Typically, summers in Leh are short, and therefore, there is a narrow window of time available for sowing of crops. In recent years, as a result of glacial and snow-pack recession, the snowline has moved up to a higher altitude. The distance between the villages and snow-pack has increased and snow-pack at higher altitudes does not melt before June (Norphel

2009). However, sowing of crops such as wheat, barley, potato, and alfalfa (which are Ladakh's staple crops) must start in April in order for farmers to be able to harvest them in September, and therefore, the entire agricultural sector is threatened as a result of delayed melting of snow (Norphel 2009). In order to adapt to these changes in weather patterns, LNP has offered expertise to rural communities in the application of some innovative technologies which are described below:

Artificial Glaciers

The concept of artificial glaciers has been developed by Mr. Norphel and his team based on ancient practices of harvesting melt-water. Artificial glaciers are large reservoirs that are created upstream of villages, which capture melt-water that would typically run off during fall and winter. This captured water is allowed to freeze during winter, and since it is collected at a lower altitude, it melts early enough to be used for irrigation in April (Norphel 2009).

Artificial glaciers are created by diverting water flowing in a natural stream via artificial channels onto slightly depressed land at a lower elevation. Water from the natural stream is diverted by a system of dams and gates for a period of 4 months from November till March. This water accumulates on the land and freezes in the winter. When it starts to melt in April, it supplies water to a downstream village that is connected to the artificial glacier by another set of constructed channels. After March, the artificial channel is blocked by a gate and the natural stream is allowed to resume its natural course (Norphel 2009). Figure 13 shows the course of a natural stream and the course of an artificial channel (under construction) diverting water from the stream in an on-going artificial glacier construction project in a village near Leh. Figure 14 shows a close-up of the dam-and-gate system used to divert water into the artificial canal. Figure 15 shows the land-bed in the background, on which the artificial glacier will be formed, with Mr. Chhewang Norphel in the foreground.

Finally, Figure 16 shows a file picture of an artificial glacier created in a village near Leh in the past, in which water has been accumulated and frozen.

Figure 13: Dammed Natural Stream and Artificial Canal in an Artificial Glacier Construction Project near Leh

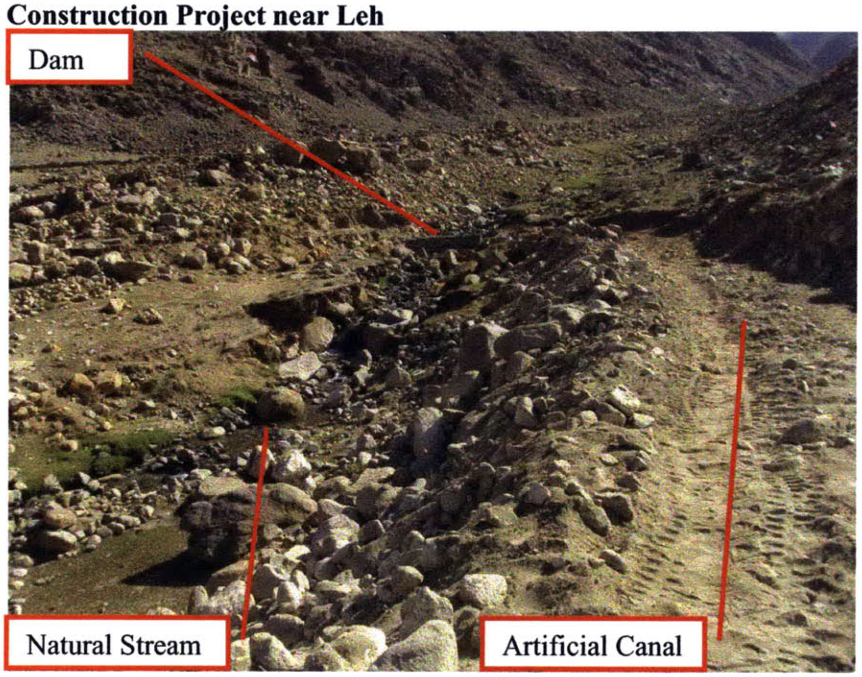


Figure 14: Close-up of Dam-and-Gate system diverting Water into the Artificial Canal

Figure 15: Land-bed on which Artificial Glacier will be formed

Figure 16: File Picture of an Artificial Glacier created in a Village near Leh

So far, 10 artificial glaciers have been constructed in Leh district under the guidance of LNP. Typically, an artificial glacier can accumulate enough water to supply irrigation water to a land area of 250 acres, or the equivalent of 200 families. On average, the cost of construction of artificial glaciers is Rs. 1,000,000 ($22,460) per project. A majority of this cost is attributable to labor (70%) and the rest is the cost of material. Funding for these projects in the past has been provided by the Central and State government (Norphel 2009). This water harvesting technique is still in an experimental stage, and will have to be tested in order to evaluate its viability as a reliable near-term solution to water scarcity.

Artificial Ponds

LNP has also constructed artificial ponds to accumulate water that trickles down from higher elevations (Norphel 2009). Land at an appropriate location is identified and a deep and wide ditch is dug to collect trickling water (See Figure 17). At the base of the ditch, local trees are planted to bind the soil such that it prevents seepage of water. No cement liners are used in the base, because this natural plant-based lining method has proven to be very effective. Water is collected in these ponds throughout fall and winter, and released in the spring (Norphel 2009). It is conveyed via channels to farmlands for irrigation (See Figure 18). The entire accumulation and delivery system works on gravity, provided that the pond is situated at a higher elevation than the fields that it irrigates. In order to prevent theft of water, the channels that carry water from the pond to the fields are regulated by valves which can be locked by village authorities (Norphel 2009).

Figure 17: View of Pond that has accumulated Water trickling down from Higher Elevations

Figure 18: Channel conveying Water from Pond to Farmlands

On average, the cost of construction per pond is Rs. 1,000,000 ($22,460), and the construction time is 2-3 months. The most recently constructed pond in a village called Sabu near Leh has been jointly funded by the Central (75%) and State (25%) government (Norphel 2009).

Snow-walls

In the Khardungla region, the direction of prevailing winds is from the south towards the north. As a result, snow gets diverted and deposited towards the north. However, it is the southern part that is primarily inhabited and has a demand for water. LNP has proposed that a feasibility study be conducted on the possibility of constructing snow-walls that block snow from being deposited in the north, and instead accumulate snow in the south. However, this method of snow accumulation has not been tested and is not likely to be implemented in the near future in Ladakh (Norphel 2009).

Ladakh Environmental Health Organization (LEHO)

LEHO is a non-profit organization and was founded in 1991. Its mission is to promote sustainable rural development and protect the social and cultural values of traditional Ladakhi societies against the negative effects of modern development (GERES India n.d.). LEHO's philosophy is based on participatory learning and action, use of local knowledge, and sustainable use of natural resources. LEHO has a watershed development program which promotes an integrated approach to water management (Deen 2009). LEHO has been engaged in watershed development projects in numerous villages in Ladakh with financial assistance from the Central government as well as LAHDC (Deen 2009). These projects include construction of irrigation canals, installation of wells, educational training on watershed concepts, and community organization. In the past, LEHO has partnered with LNP extensively to build artificial ponds and glaciers in villages of Ladakh (Deen 2009).

Defense Institute for High Altitude Research (DIHAR)

DIHAR is one of the research laboratories of the Defense Research & Development Organization (DRDO) under the Ministry of Defense, Government of India. DIHAR was created under the directive of Jawaharlal Nehru, India's first prime minister, in response to the need for research and development on agricultural science and technology in Leh's harsh climate in order to sustain the local population as well as military and paramilitary forces deployed in the region (Defense Research and Development Organization, Ministry of Defense, Government of India 2010). Ladakh is an extremely important strategic location for Indian military operations and has hosted a large military base since 1962, when India faced border disputes with China. The presence of the military became stronger after the India-Pakistan conflicts in 1965 and 1971, and most recently in 1999. As a result, the need to provide basic amenities such as water and nutrition to the inhabitants of the region is greater than ever (Stobdan 2010). For example, a senior scientist at DIHAR stated that the requirement of vegetables in Leh's military base is 600 metric tons per year, and approximately 60% of this requirement is met locally, implying that the demand for water in the agricultural sector in Leh has increased substantially. Moreover, this demand is likely to continue to increase, as one of DIHAR's goals is to be able to increase the productivity of the local agricultural sector in order to mitigate the cost of importing food resources from other parts of India (Stobdan 2009).

DIHAR has conducted research on climate resistant varieties of crops and vegetables and sustainable agricultural practices that minimize the use of water. For example, DIHAR's research strongly suggests that drip irrigation[22] and mulching[23] are extremely effective mechanisms of conserving water in Leh's climate (Stobdan 2009). Figure 19 shows an experiment testing the efficacy of mulching in preventing evaporation of moisture from the soil in a small plot of agricultural land on DIHAR's property.

Figure 19: A Test of the Efficiency of Mulching using a Plastic Liner

This research has high pertinence for urban Leh, because there is extensive urban agriculture practiced within the town. In fact, PHE estimates that approximately 20-30% of drinking water supplied to residents of urban Leh is used for agricultural purposes (Kaul 2009). Additionally, the increasing local, military, and tourist population has given rise to a demand for highly water-intensive agricultural produce that is not native to Ladakh. For example, the cultivation of

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[22] Drip Irrigation is a method of irrigation in which water is released at the root zone of crops very slowly via small pipes and emitters (Stobdan 2009).

[23] Mulching is a practice of using a protective covering over soil such as plastic to prevent the evaporation of moisture from the soil (Stobdan 2009).

potatoes is much more profitable than the cultivation of local crops because there is a greater demand for potatoes, and therefore, such economic incentives in the agricultural sector result in additional consumption of water (Norphel 2009).

Given the region's high reliance on agriculture, it is clear that DIHAR will play a very important role in making agriculture in Ladakh more sustainable. DIHAR has access to substantial resources because it is part of the Ministry of Defense. But at the same time, DIHAR is the only research organization under the Ministry of Defense that is accessible to the general public. DIHAR's work is openly shared with local farmers, and therefore, it has the potential to enhance conservation of water in urban Leh's agricultural sector (Stobdan 2009).

From this evidence of efforts among various groups of stakeholders to address water scarcity in Ladakh, it can be concluded that while the local government has been alerted to the saliency of water scarcity issues, the government's primary strategy continues to follow conventions of supply augmentation, with little focus on water conservation. Moreover, parallel to government efforts to manage water issues, there is evidence of initiatives taken by civic society in the area of water resources management, but these organizations seem to be largely focused on rural environmental challenges, and have not engaged in water-related projects in urban Leh.

Chapter 7: Responses, Drivers, and Barriers to Adaptation in Dharamshala and Leh

Dharamshala and Leh are facing multifold impacts on their water resources as a result of increasing demands for water (due to economic development) and decreasing supplies (due to climate change). Given the impacts of these different factors on the water availability of the two towns, it is necessary to understand how these towns approach the issue of water scarcity (i.e. whether water scarcity is perceived as a demand problem, or a supply problem, or both). Based on the responses to water scarcity that have occurred so far in Dharamshala and Leh, patterns can be observed in the ways these towns have defined the challenge of water scarcity, and in the planning/implementation measures that have been taken to resolve this challenge. The way these towns define water shortage may be linked to whether climate change is perceived as a salient causal factor by their governance institutions, and in turn, determines if future planning and implementation in the towns should be carried out within the framework of climate change adaptation.

This chapter analyses the primary drivers of planning and implementation measures that have taken place in Dharamshala and Leh in response to water scarcity, and identifies whether these measures take into consideration the additional impacts of climate change on the towns' water resources. Simultaneously, barriers to a more progressive, holistic, and anticipatory form of adaptation (not just to water scarcity as a result of increasing demand, but scarcity in the context of climate change) are identified on the basis of observations made about the management of water resources in both towns' water agencies. The first section of the chapter presents a summary of observations important to the subsequent analysis in this chapter. The second section highlights similarities and contrasts seen in the case-studies in terms of their water management strategies. Based on these comparisons, the primary motivations behind the choice of strategies embraced in Dharamshala and Leh are revealed. In particular, it is examined in this section, whether climate change has featured at all among the factors considered in the decision-making processes governing the water management of Dharamshala and Leh. The final section of the chapter offers examples of barriers that have prevented these towns from effectively arriving at long-term, sustainable solutions to the continual challenge of water scarcity. Specifically, explanations are offered for why climate change considerations have been absent in the planning processes of the towns to date, based on the premise that taking the impacts of climate change into account is an important prerequisite to finding sustainable solutions to water scarcity in Dharamshala and Leh.

Summary of Observations

Prior to analysis, it is helpful to summarize key characteristics of the towns of Dharamshala and Leh along with the peculiarities of their water management. Table 14 presents a comparative review of the various demographic, geographical, political, and socio-economic characteristics of the two towns.

A comparison of the populations of the two towns in Table 14 shows that both towns are small compared to Indian standards. However, the population density of both towns is much higher than the average density of their surrounding regions. For example, according to the census of 2001, the density of Kangra District is only 223 persons/sq. km (See section on "Demographics" in Chapter 5). The density of Ladakh is even lower at 6 persons/sq. km (See section on "Demographics" in Chapter 6). Thus, it is clear that these two urban centers exert much more pressure on the natural resources of the region compared to surrounding areas. Both towns are expected to experience substantial population growth in the next few decades.

Dharamshala's population will increase by 58% of its 2009 population by the year 2015, whereas Leh's population will increase by 53% of its current population by the year 2025. Table 14 also compares the per capita income of the States of Himachal Pradesh and J&K (State averages are used because town-level per capita income was not available). This comparison shows that the per capita income of Himachal Pradesh is almost three times higher than that of J&K (See sections on "Socio-economics" in Chapters 5 and 6). Even though the reported incomes are for different years (i.e. for Himachal Pradesh, the reported income is for 2007, whereas for J&K, the data is from 2004), it is clear that Himachal Pradesh is significantly wealthier than J&K and has a better literacy rate. Additionally, the percentage of non-agricultural workers in Kangra District is higher than that in Leh District, implying a possible correlation between non-agricultural sectors and higher incomes (See sections on "Socio-economics" in Chapters 5 and 6).

The role of non-agricultural sectors is especially important in the context of Dharamshala and Leh, as they are urban centers. It has been mentioned that both towns have attained high cultural, religious, and spiritual significance which has led to an expansion of the local tourist industry. Additionally, these towns are embedded in unique ecosystems within the Himalayas, and although their topographies are very different (Dharamshala has dense vegetation, whereas Leh is largely arid and barren), both towns have gained popularity among tourists on account of the pristine environment of the regions in which they are located. Thus, Dharamshala and Leh have followed similar trajectories in terms of urbanization and economic development. However, their political history has been quite different. While Dharamshala has seen stability in its government following the integration of Himachal Pradesh into the Indian political system, Leh has been in conflict with higher orders of governance like the J&K government and the Central Government on account of its autonomous status (See section on "Government and Administration" in Chapters 5 and 6). Consequently, the structure of administration in Dharamshala and Leh is also quite different, in that it is more centralized in Dharamshala, and decentralized in Leh.

Table 14: Summary of Observations in Dharamshala and Leh

Characteristics	Dharamshala	Leh
Population	34,036	38,000 (average)
Population Density (persons/sq. km)	1,136	2,000 (average)
Projected Population Growth Rate (%)	58% (from 2009 – 2015)	53% (from 2009 – 2025)
Per Capita Income (State Average) (Rs./Capita)	Rs. 33,283 (2007)	Rs.12,399 (2004)
Percent Literacy in year 2001) (%)	80.08% (Kangra District)	62.24% (Leh District)
Indicators of Urbanization and Economic Development	Growth in population, tourism, and shifts to non-agricultural service industries	Growth in population, tourism, and shifts to non-agricultural service industries
Percent Non-Agricultural Employment	40.86% (Kangra District)	33.66% (Leh District)
Cultural/Religious/Spiritual/ Political Significance	Refuge for Tibetans in exile	Influences of Buddhism, role in national security
Tourist Attractions	Pristine environment, spiritual learning	Pristine environment, spiritual learning, adventure sports
Evidence of Political Turmoil	Minimal	Strong
Structure of Administration	Centralized	Decentralized

In light of the demographic, geographic, political, and socio-economic characteristics of the two towns and their surrounding regions, the various characteristics related to water resources in the two towns are presented in Table 15.

Table 15: Summary of Water Management Characteristics of Dharamshala and Leh

Characteristics	Dharamshala	Leh
Structure of Water Management	Centralized	Decentralized
Participation of Civil Society in Water Issues	Minimal	Extensive
Climate parameters governing water sources	Rainfall, snowfall, temperature	Snowfall, temperature
Traditional Water Sources	Streams, springs	Streams, springs
Newly Explored Water Sources	Groundwater, streams	Groundwater
Magnitude/Duration of Water Scarcity	Moderate/Seasonal	Acute/Perennial
Per Capita Water Consumption in Domestic Sector (LPCD)	30	17 (average)
Percent Households with Private Municipal Water Connections	86%	4%
Water Supply Duration (hours/day)	2 (average)	2 (average)
Cost of Water Production (Rs./KL)	Rs. 15[24]	Rs. 15[22]
Type of Tariff Model	Metered	Non-metered, fixed-price
Percent Subsidization of Domestic Supply	70%	Not Applicable
Percent Subsidization of Commercial Supply	40%	50%
Percent 'Unaccounted for' Water Supply (%)	25-50	Not known
Percent Withdrawal from Available Discharge in Supply Sources (Table 5) (%)	54%	Not known
Perceptions of Causes of Water Scarcity	Population growth, economic development, climatic changes	Population growth, economic development, climatic changes
Acknowledgement of the need to address water scarcity in the context of climate change	Weak	Weak

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[24] This estimate of the cost of water production is based on the national average water production cost in urban areas in India. The average costs of water production in Dharamshala and Leh were not shared by the water agencies as they did not have updated calculations of this cost, and therefore, the national average cost of water consumption is used as a surrogate in estimating the percent subsidization of water in Dharamshala and Leh, under the assumption that the water production cost in these two towns is close to the national average.

For example, the structure of administration in the local governments of Dharamshala and Leh influences the way the water agencies in the two towns operate. Water management in Dharamshala is more centralized than it is in Leh (See section on "Institutional Structure of Water Management" in Chapter 5). Conversely, there is a stronger presence of civil society actors in the area of water management in the Ladakh region as compared to Dharamshala (See section on "Other Efforts on Adaptive Management of Water Scarcity in Leh" in Chapter 6).

The primary source of water in Leh is snow-pack, whereas in Dharamshala, water comes from two snow-pack as well as rainfall (See section on "Evidence of Climatic Changes and Shrinking Water Supply" in Chapters 5 and 6). Consequently, scarcity in Dharamshala is largely seasonal (i.e. it occurs during the months of March, April, and May), whereas scarcity in Leh is much more acute and perennial.

Given these differences in the extent of water resources available to the two towns, it is helpful to define the magnitudes of water stress faced by the two towns based on standardized definitions. For example, IPCC uses an index developed by Falkenmark and Lindh (1976) to categorize water stress in a region based on the amount of water withdrawn as a percentage of total available water resources in that region. In this categorization, the regions in which over 40% of total available water resources is withdrawn are denoted as regions facing the highest magnitude of water stress (IPCC 2001).

While IPH in Dharamshala has some records of the amounts of water withdrawn and total available discharge in its supply sources, data in Leh is limited to just the quantity of water withdrawn from supply sources. In other words, there is no monitoring of total discharge in the supply sources of water in Leh. As a result, while it may be possible to estimate the extent to which Dharamshala extracts water from current available sources, and define water stress based on this percentage, there isn't enough information to derive the same calculations for Leh. Nonetheless, for Dharamshala, based on the data in Table 5, which describes total wet and dry period discharge, and amount of water withdrawn, it is estimated that in dry season, 54% of total available discharge in the supply sources of Dharamshala is withdrawn, implying that the town experiences high levels of water stress (See section on "Traditional Sources of Water Supply" in Chapter 5 for calculations of water stress). It should be noted that this calculation does not take into account the full extent of groundwater resources available to Dharamshala, as well as the amount of extracted groundwater that goes unmonitored in the town. However, this preliminary calculation gives some estimate of the magnitude of water stress faced by Dharamshala in the dry season. In Leh, even though the lack of appropriate data does not allow for the quantification of the magnitude of water stress in the town, it is safe to assume that water stress levels in Leh are probably higher than those in Dharamshala, given the climatic and hydrological characteristics of the town.

It follows from these differences in annual availability of water in the two towns, that the percentage of households with access to private municipal water connections in Dharamshala is much higher than that of Leh, and the per-capita consumption of water in Dharamshala is greater than that in Leh (See section on "Traditional Sources of Water Supply" in Chapter 5 and "Status of Water Use" in Chapter 6).

In terms of the daily duration of water supply, rationing has been enforced in both towns and therefore, water supply is limited to approximately 2 hours per day, and my be reduced even further depending on availability (See section on "Institutional Structure of Water Management" in Chapter 5 and "Institutional

Management of Water" in Chapter 6). In the absence of data on the water production cost in Dharamshala or Leh, the national average water production cost in urban areas in India is used as a reference based on the assumption that the water production cost in Dharamshala and Leh is approximately similar to the national average. Using this reference average water production cost of Rs. 15/KL, it is approximated that 70% of the domestic sector's water supply in Dharamshala is subsidized. In Leh, on the other hand, since water supply is not metered, and since only 4% of the domestic has private municipal water connections, it can be assumed that the rest of the domestic sector relies on PSPs (which are not priced by PHE) or other means of water supply like barrels or tankers. Therefore, the public water supply in the form of PSPs appears to be fully subsidized. Cost recovery in the commercial sector is slightly higher in both towns. In Dharamshala, if the same average water production cost of Rs. 15/KL is assumed, then approximately 60% of the cost of water services is recovered from the commercial sector, implying that 40% of commercial water supply is subsidized. In Leh, calculations based on the average quantity of water consumed by large hotels, and the reference national average water production cost suggest that approximately 34% of commercial water supply in Leh is subsidized.

In addition to subsidies, another reason why cost recovery in the two towns is low is because a large amount of water extracted from sources does not actually make it to end users. The percentage of 'unaccounted for' water in both towns is estimated to be significantly high. In Dharamshala, 25-50% of the total water supply is believed to be lost to leakages and other defects in the supply infrastructure (See sections on "Gaps between Supply and Demand" in Chapters 5 and 6). In Leh, while the percentage of lost water has not been formally quantified, it can be assumed that this percentage is similar to that found in Dharamshala, based on qualitative observations that have been made in past studies.

In efforts to close the gaps between supply and demand faced by both towns, groundwater resources have been explicitly identified as the key to solving water scarcity challenges in both towns (See sections on "Efforts to Address Supply-Demand Gap" in Chapters 5 and 6). Lastly, population growth and goals of economic development appear to be serving as key drivers of policy/planning action in both towns. Additionally, while general awareness of local climatic changes exists in both towns, climate change considerations have not been explicitly mainstreamed into town planning. The findings on economic development and population growth as drivers of water-supply augmentation strategies employed by the water agencies in the two towns, along with the absence of climate change considerations in their planning processes is discussed in greater detail in the subsequent sections of this chapter. Thus, given this summary of characteristics of the two towns, an analysis of the similarities and differences in the two towns is presented in the next sub-section of this chapter.

Similarities between Case Studies

There are some very prominent similarities in the responses of both Dharamshala and Leh to water scarcity that have emerged in the last few decades. While Leh faces more acute water shortage than Dharamshala for a longer duration of the year, the supply of water in both towns has been lagging behind demand for the past few decades, particularly given the growth in the local population, urbanization, and tourism. Consequently, the most direct short-term means of coping with reduced reserves of water has been through daily rationing, i.e. limiting the supply of water made available per day (Tandon 2009 and Kaul 2009). In both towns, rationing of water during periods of acute scarcity has been practiced on a regular basis, during which daily water supply may be reduced from two-three hours to one-two hours, or at times, less than a half hour (Tandon 2009 and Kaul 2009), thereby aggravating the existing non-uniformity of water distribution within the town. This practice is not atypical in most urban areas of India or other similar developing nations, for that matter (Cairncross, et al. 1993) and is indicative of the reality that most regions of India do not have the luxury of a 24-hour water-supply.

As far as medium-term responses to water scarcity are concerned, to date, both towns have relied mostly upon supply augmentation to meet the increasing demand for water and as a response to the decreasing viability of existing supply sources. This can be attributed to the compartmentalized responsibilities of the water management agencies in charge of providing water to the towns, namely, IPH and PHE. Both agencies perceive themselves as water-supply agencies, and have not explicitly considered the adoption of other aspects of water management such as conservation, storm-water management, and wastewater management, and how these aspects may help close the gap between water supply and demand. For example, when the executive engineer in PHE was asked if PHE had a focus on conservation of water, he replied that PHE's responsibilities were strictly limited to water supply (Kaul 2009). Similarly, the chief engineer at IPH (Dharamshala) mentioned that the goal of IPH is to ensure adequate supply of water to the town (Tandon 2009). This implies that both IPH and PHE have perceived their responsibilities to be limited to finding new sources of water in order to keep up with increasing demand.

Another reason for the focus on supply augmentation is the rapid population growth, urbanization, and economic development being experienced (and being prioritized) by both towns. In Dharamshala, for example, by the year 2015, the resident population is estimated to increase by 58% of its current population (See Table 2). This will result in an increase in the resident population's demand for water by approximately the same magnitude (See Table 7). Similarly, in Leh, the average population will increase by 46% of its current population in the year 2025, and 100% of its current population in the year 2040 (See Table 9). As a result, by 2040, the demand for water in Leh is expected to double the current demand (See Table 13).

Additionally, both towns have a rich cultural and natural heritage that has attracted a growing tourist industry, which the local governments of both towns are keen to promote. For example, in Dharamshala, the number of hotel and guest-house beds will increase from 977 in 2009 to 1550 in 2015, and this is accounted for in the projected demand for water in Dharamshala in 2015 (See Table 7). Similarly, in Leh, the number of hotels has increased by 130% since 1999 and there trend is likely to continue under the current structure of subsidies provided by the Leh Development Authority to hotel construction projects (Akhtar 2010). This growth in the tourist industry in both towns will contribute significantly to the increase in the demand for water. The municipal councils of both towns are unequivocal in their encouragement of tourism as a strategy for economic development. For example, the Chief Executive Councilor of Leh stated explicitly that PHE needs to accommodate the tourist industry in its plans to secure a reliable supply of water for Leh in the coming decades (Dorjay 2009). Similarly, according to the chief engineer at IPH, this agency is expected to take the projected increase in the number of hotels and guest-houses as a given, and make arrangements to meet the increasing demand for water accordingly (Tandon 2009). Thus, it seems that the inevitability of a growing tourism industry is assumed in both towns, and the manner of its growth is not questioned despite the existing knowledge of its impacts on water resources.

Moreover, in the case of Leh, its geographic location also makes the town strategically important for national security and therefore, Leh has been supporting a military base since the 1960s, which has been expanded considerably since the most recent armed conflict at Kargil between India and Pakistan in the late 1990s (Stobdan 2009). According to a senior scientist at DIHAR, the nutritional needs of the expanding military base have been explicitly prioritized by the Central Government among other needs, and as a result, the demand for water resources exerted by the military in Leh is only expected to increase. Thus, increasing the water supply is being viewed as a means of sustaining economic development, urbanization, population growth, and other activities like military operations in Dharamshala and Leh. All said and done, the per capita water consumption in both towns is well below the nationally prescribed minimum water requirement of 135 liters for cities in which a sewage system exists or is being contemplated. In Dharamshala, the actual average per capita consumption of water in the domestic sector is estimated to be not more than 30 LPCD (Sterkele, et al. 2003), and in Leh, it is estimated to be between 14-21 LPCD (Akhtar 2010). According to the executive engineer at PHE and the chief engineer at IPH, neither town has 100% access to piped water. Moreover sanitation coverage / sewage treatment are far behind piped water supply (Kaul 2009 and Tandon 2009). Thus, in light of the goals of the local government to improve the standard of living of its constituents and sustain other important sectors such as tourism and the military, supply augmentation is not just an approach arising from the narrow expertise and outlook of the water agencies, but a desirable strategy for the development of Dharamshala as well as Leh.

Another similarity in the two case-studies lies in the reactive institutional services provided by the water agencies of both towns. In terms of daily institutional operations, it is junior engineers who are the most familiar with the status of water supply services on the ground. However, junior engineers in both towns are primarily engaged in addressing complaints or requests from consumers as they arise. As a result, their daily responsibilities (which primarily include reactive responses such as repairing recurring defects in the supply system) are extremely time-consuming and make it difficult for junior engineers to engage in proactive planning for the improvement of the agencies' services via consultations with senior management. For instance, it was observed that scheduling interviews with junior engineers was extremely challenging, as they were busy addressing complaints or overseeing expansion projects. Moreover, when they were interviewed, it was sensed that while they were very familiar with the operational details of the town's water supply, they did not seem comfortable answering open-ended queries on how the performance of the water agencies could be improved, despite their familiarity with the characteristics of the respective towns' water supply systems (Kapoor 2009 and Tashi 2009).

In general, based on interactions with the staff members of both agencies, a lack of motivation and a tendency to maintain status quo was perceived among the junior staff. Creativity or foresight seemed to be lacking, and it was perceived that the staff was uncomfortable with exploring or responding to ideas beyond their immediate scope of responsibilities. It was also sensed in both agencies, that there was a lack of familiarity among the staff members about each others' roles and responsibilities. For example, if administrative assistants were approached with queries about whom to contact within the agencies for particular information, their responses were often found to be less than helpful.

Additionally, the predominant work-culture in both agencies in the line of management was found to be highly technocratic: staff members at all levels possess a background in engineering, with little evidence of the inclusion of planners, economists, or social scientists in the processes governing decision-making related to water resources. As a result, solutions to water scarcity put forth by both agencies have been predominantly technology-centric. For example, in the recent past, (since the late 1990's) water agencies in both towns claim to have discovered groundwater as an abundant resource and a viable alternative to the traditional surface sources of water supply (See section on "Efforts to Address Demand-Supply Gap" in Chapters 5 and 6)). When asked about how PHE planned to ensure a reliable supply of water to Leh, the executive engineer of PHE replied that groundwater resources were the "only long-term solution" to Leh's water shortage problems (Kaul 2009). Similarly, according to a superintending engineer in IPH, groundwater is a highly viable resource for Dharamshala in the future due to its geographic location and climate (Malhotra 2009).

In fact, these claims are supported by local academicians and consultants in both Leh and Dharamshala. For example, an academician in the Government College, Dharamshala, stated in an interview that the geographic location of Dharamshala is highly favorable for groundwater recharge because melt-water from the Dhauladhar Mountains seeps into the ground at the elevation and location where Dharamshala is situated (Dhar 2009). Similarly, an independent consultant who is familiar with water resources in the Ladakh region stated in an email correspondence that while groundwater was initially considered to be non-viable in the Ladakh region, its potential has been established since the 1990s and groundwater development projects have been quite successful in Ladakh. He further stated that groundwater holds the key to solving the water problems of this region (Arya 2009). Lastly, the findings of Tetra Tech's report also identify portions of Leh that have good groundwater extraction potential (Tetra Tech 2009).

Thus, in summary, it seems that local experts in both towns are claiming that groundwater sources are the key to securing water provision and consequently, groundwater extraction is being promoted based on what appear to be somewhat superficial, preliminary feasibility studies. However, in the absence of measures to ensure the sustainability of these groundwater resources and to prevent over-extraction, it is not certain if groundwater can be counted upon as a long-term solution to the water shortage faced by both towns.

Contrasts between Case Studies

Parallel to the similarities observed in the two case studies are also some profound differences in the management of water by the water agencies. The first is in the institutional structure of water management. While PHE in Leh is fairly decentralized, and reports directly to the LAHDC, IPH in Dharamshala is a branch of a State Government agency. There seem to be advantages and disadvantages to both these structures. For example, in Dharamshala, the chief engineer at IPH stated in an interview that he was responsible for the overall management of the water supply in Kangra and Chamba Districts of Himachal Pradesh, and while he was familiar with the general details of daily water management in the particular town of Dharamshala, he delegated most daily responsibilities to his subordinates (Tandon 2009). Thus, it appears that in Dharamshala, upper management in the State-Government-run office tends to overlook the nuances of daily water management at the local scale, leaving the daily challenges of the town's water supply to junior staff that does not have the time or resources to participate in the planning of long-term reforms to water services.

However, centralized water management for the entire State of Himachal Pradesh enables the town of Dharamshala to operate within the framework of State guidelines such as the Himachal Pradesh Water Policy and the Himachal Pradesh Groundwater Act (Department of Irrigation and Public Health 2005), both of which, in theory at least, are holistic water policies that the town of Dharamshala could embrace. Centralized management also makes it easier for the town to receive top-down assistance, particularly if the municipality of concern is an asset to the State. For example, after the IPH took over the responsibility of water management from the Municipal Committee in 1986, significant reforms were made via investment in financial and technical resources by the State-Government-run IPH (Department of Irrigation and Public Health 2009). This is an important advantage, given that water services in Dharamshala are subsidized, particularly in the domestic sector. Under this pricing structure, the town will continue to require financial assistance from the State and Central Governments. Consequently, according to a chief engineer in IPH, most infrastructure-intensive water-resource development projects in Dharamshala are primarily funded by the Central Government, and managed by the State Government, and there is little evidence of the involvement of the civil society sector in issues of water management in Dharamshala (Tandon 2009).

In Leh, on the other hand, decentralized management of water has enabled the PHE sub-division in Leh to exercise autonomy over the management of water, thereby enabling the agency to cater specifically to the needs of the town. The responsibility of the executive engineer of PHE's sub-division in Leh is primarily for the town of Leh. Based on interviews, it appeared that he was well-versed with the fundamentals of Leh's water supply system. For example, he had the most current and detailed knowledge of which springs among Leh's water supply sources were serving at reduced capacity (Kaul 2009). Thus, it can be argued that the senior management's familiarity with the nitty-gritty of the town's water supply places PHE is a better position to take informed measures to improve the performance of PHE. However, the autonomy of PHE's Leh sub-division in the context of LAHDC's historical conflicts with the State and Central Governments also puts PHE at odds with the higher orders of government, likely creating complications in the flow of governmental assistance from top to bottom. For example, a LEDeG member voiced concerns about the stability of the current ruling party in LAHDC and its implications for management of water resources in the town (Hasnain 2009). Moreover, the absence of an overarching water policy reduces incentives to bring about reforms in the management of water resources beyond just the bare minimum strategies currently used by PHE. This has led to a reinforcement of how PHE perceives itself as a water supply agency. As in the case of Dharamshala, water supply in Leh is also subsidized, and PHE does not have the resources to spearhead infrastructure expansion/improvement without financial assistance from higher levels of government. In the past, for example, among PHE's numerous supply augmentation schemes, a substantial portion of funding has come from the Central Government (National Informatics Center, Leh District, Ladakh, n.d.). However, given the turbulent politics surrounding the most recent elections in Leh, it has been pointed out by civil society actors that there may be political barriers to bringing about beneficial reforms in a local agency if it is in conflict with higher levels of government (Hasnain 2009).

Another contrast that has been identified between the two case studies is the level of participation of civil society in environmental issues like water management. There isn't a high level of participation of civil society in Dharamshala, particularly in the area of water management. This has been attributed to the fairly centralized management of water resources by the Himachal Pradesh State Government, which, over the years, has created a comprehensive framework for water management in rural as well as urban areas (Tandon 2009). Conversely, there is a strong presence of environmental organizations in Ladakh (albeit mostly in rural areas), which can be explained by the political history of Ladakh. Literature suggests that the mobilization of civil society in Ladakh has been due to the challenges faced by LAHDC on account of its limited organizational, technical and financial capacity (Aggarwal 2004). It should be noted, however, that civil society's involvement in Ladakh wasn't just a consequence of the institutional challenges faced by LAHDC, but in fact, originated in conjunction with demands for the creation of LAHDC (Aggarwal 2004). LAHDC was instituted at a time when Ladakhis were disillusioned with the promise of development and there were strongly opposing views over the Central Government's modern vision for Ladakh versus that of the local community groups. Investments made by the Central Government in the development of Ladakh were not reaping high returns. Development often came with the conditionality of homogenization and therefore, and under such conditions, disparate ethnic groups found it difficult to maintain themselves as culturally plural domains (Aggarawal 2004). Simultaneously, debates about the practicality of applying generic constructs of economic development to a remote region like Ladakh were rampant in the early 1990s, as evidenced by Helena Norberg-Hodge's book: *Ancient Futures: Learning from Ladakh*. Ladakh was often described by foreigners as a "haven of sustainable development and the last frontier in the war against modernity's development hoax with its malaise of environmental degradation, fragmented social relations, and loss of self-sufficiency" (Norberg-Hodge 1991). At that point, LAHDC was perceived as a governmental body that would be able to bring development to Ladakh while preserving its cultural integrity (Aggarwal 2004).

But given the subsequent difficulties that LAHDC has encountered, environmental community organizations have stepped up to advocate culturally sensitive development in Ladakh. According to a representative from LEHO, among various assignments, community organizations in Leh are engaged in multiple parallel projects to help the rural Ladakhi community obtain enhanced access to water resources in an effort to sustain their traditional ways of living (Deen 2009).

However, the lack of involvement of community organizations in environmental challenges faced by urban Leh is conspicuous, particularly in the context of Ladakh's historical outlook on the environment and unsustainable economic development. This indicates a departure from LAHDC's and the Ladakhi people's original philosophy on conservation versus development at least as far as management of urban Leh is concerned. When asked about the reasons why civil society has not played an active role in the water management of urban Leh, staff members of community organizations have pointed out that their traditional areas of intervention have been geared towards goals of helping underprivileged populations in disadvantaged areas (Deen 2009 and Norphel 2009). Moreover, the objectives of most of these organizations have been consistent with goals of preservation of culture, traditional economy, and the environment in Ladakh. Since urban Leh has departed from these traditional values, it has led to a concentration of civil society efforts primarily in rural areas, with the hope that these values will be preserved in those areas (Deen 2009). Moreover, it has also been pointed out by a representative from LNP, that processes of project planning and implementation in urban areas can be much more complicated compared to rural areas. For example, when asked about the applicability of traditional methods of water harvesting (like ponds or artificial glaciers) in urban Leh, the representative stated that legal issues such as land-use regulation and management in urban areas are much more complex than they are in rural areas, and there would be difficulties at the very initial stages of project planning in identifying appropriate land for water harvesting (Norphel 2009). Due to these various reasons, ultimately, despite the presence of civil society in Ladakh, its influence on environmental management in urban Leh seems to be limited, whereas in Dharamshala, involvement of civil society seems to be absent altogether. However, it appears that the forms of governance in Dharamshala and the region of Ladakh (i.e. centralized versus decentralized governments) have influenced the level of participation of civil society actors in issues such as water management.

Another notable difference between Dharamshala and Leh lies in the extent to which the future of water resources in both towns has received salience. It is evident that the magnitude of water scarcity has influenced the level of effort being invested in addressing water scarcity in the two towns. While Dharamshala receives abundant rainfall during the monsoons (Hotels in Dharamshala n.d.), Leh lies in the rain shadow region of the Himalayas (National Informatics Center, Leh District, Ladakh n.d.). In Leh, water scarcity is perennial as the town has traditionally relied on water bodies primarily fed by snow-pack. Conversely, Dharamshala has been found to experience scarcity only during the dry season for approximately three months (March, April, and May) (Department of Irrigation and Public Health 2009). Consequently, as the dry season approaches its end in Dharamshala, water scarcity tends to lose salience for the rest of the year, thereby not prompting long-term planning action to address temporary scarcity in the summer. Indeed, the general consensus among senior management in IPH is that there is currently no need to fear the possibility of acute water scarcity in the near future (Tandon 2009).

Consequently, Dharamshala's latest action plan for water-resource development accounts for water requirements only until the year 2015. What happens after that is admittedly beyond IPH's current estimation capabilities. According to the chief engineer in IPH, there was some discussion in August 2009 of commissioning a new study to account for the town's water supply for the following two decades, but it has not been formalized (Tandon 2009). This suggests that water scarcity is not being perceived as an imminent threat in Dharamshala, and is being coped with on a periodic basis, as it arises. In contrast, LAHDC has already completed a study to determine future courses of action in the management of its water resources, which accounts for water needs up to the year 2040. Whether the recommendations made in this study are sustainable is highly debatable, but nonetheless, PHE's investment in this study is indicative of the fact that the future of water management does feature among the LAHDC's priorities. For instance, the chief executive councilor of LAHDC stated that the future of water resources in Leh was an integral component of Leh's most recent urban development plan (Dorjay 2009). Thus, in terms of preparedness, it appears that the government of Leh is taking the long-term future of water resources into consideration in its development plans, whereas the government in Dharamshala has been managing water resources on a more short-term basis, and one of the reasons for this difference is the magnitude of water scarcity faced by the two towns on a yearly basis.

Drivers of Action

The similarities and differences drawn from the case studies offer insights into the primary motivations behind the actions that governments in Dharamshala and Leh have taken to address water scarcity. In both towns, supply augmentation has been the primary strategy used to meet the growing demand for water. The rationale for this strategy can be explained by a number of factors, which are discussed below:

As mentioned earlier in this chapter, Dharamshala's population is expected to increase by 58% of its current population by the year 2015, which will cause an increase in the demand for water in the domestic sector by the same magnitude. Similarly, Leh's average population will increase by 100% of its current population by 2040, as a result of which, the demand for water in Leh is expected to double the current demand (See Table 13). The local governments of both towns use nationally prescribed standards for minimum acceptable daily water consumption per capita (120 LPCD in Dharamshala, and 135 LPCD in Leh) as a benchmark, which is interesting because the current per capita consumption of water in both towns in the domestic sector is much lower than these prescribed standards (approximately 30 LPCD in Dharamshala and between 14-21 LPCD in Leh). The water management agencies in both towns have been directed to use these standards in the future planning of water resources. For example, according to the chief engineer at IPH, Dharamshala, when IPH first took over the responsibility of water management in Dharamshala, a standard of 70 LPCD was used as a minimum acceptable rate of water consumption per capita, and was instituted as a goal until 2005, after which it was increased to 120 LPCD (Tandon 2009). This indicates that the local government has called for an improvement of development indicators like per capita water consumption, with the ultimate goal of increasing the standard of living of its constituents.

It has also been mentioned earlier, that the cultural and natural heritage of both towns has attracted a growing tourist industry, which the local governments of both towns are keen to promote. For example, in Dharamshala, the number of hotel and guest-house beds is projected to increase from 977 in 2009 to 1550 in 2015, and this has been accounted for in the projected demand for water in Dharamshala in 2015. According to the chief engineer at IPH, this agency is expected to take the projected increase in the number of hotels and guest-houses as a given, and make arrangements to meet the increasing demand for water accordingly (Tandon 2009). Similarly, in Leh, the number of hotels has increased by 130% since 1999 and there trend is likely to continue under the current structure of subsidies provided by the Leh Development Authority to hotel construction projects (Akhtar 2010). It follows that this growth in the tourist industry in both towns will contribute significantly to the increase in the demand for water, in addition to the population growth factors mentioned above.

The municipal councils of both towns appear to be unequivocal in their encouragement of tourism as a strategy for economic development. For example, the Chief Executive Councilor of Leh stated explicitly that PHE needs to accommodate the tourist industry in its plans to secure a reliable supply of water for the town of Leh in the coming decades (Dorjay 2009). In fact, in the case of Leh, given how urban Leh has departed from the traditional Ladakhi subsistence economy, and has embraced those values of economic development which have historically been rejected by the people of Ladakh (Aggarwal 2004), the goals for economic development appear to be especially strong. Moreover, literature suggests that the local motivations for economic development in both Dharamshala and Leh seem to reflect those for growth in the respective State Governments of Himachal Pradesh and J&K, and the measures taken by these State Governments to promote economic development. These efforts have shown substantial results at the State level, in that the GDP of both States has increased by over 80% from the period between 2000-01 and 2006-07, and has continued to increase in subsequent years (Government of Himachal Pradesh 2007 and IBEF 2009).

Therefore, it is clear that the goals set by the local governments of Dharamshala and Leh for urbanization and economic development are consistent with those of their respective State Governments, and in turn, are strongly reflected in the management of the towns' urban water services. In other words, water resources are viewed as a means of achieving the goals of economic development that have been prioritized by the local governments of Dharamshala and Leh. Based on these observations, it is concluded that the primary driver for the towns' supply augmentation approach has been economic development with the purpose of raising the living standards of the local population.

It follows from this evidence of rapid investment in economic development in both towns, that the current and future impacts of climate change are largely unaccounted for as governance institutions in both towns make arrangements to meet the growing demand for water. Despite the existence of implicit awareness among individual government officials as well as other stakeholder groups in Dharamshala and Leh about local climatic changes and their impacts on water resources, climate change has not been explicitly mainstreamed into the future development plans of any of the government departments of either town (Tandon 2009 and Kaul 2009).

Given these findings of the primary drivers of Dharamshala and Leh's current approach to water scarcity, and the absence of climate change considerations in decision-making, it is important to compare the findings to existing theory on drivers of action and the importance of climate considerations. There is emerging literature on climate change adaptation which suggests that proactive adaptation is motivated by local goals and priorities (See Chapter 2). Specifically, a commitment to development has been cited as one of the most common motivations for city governments to initiate adaptation measures (Sippel, et al. 2009). Dharamshala and Leh present an interesting comparison to this emerging evidence in adaptation theory. On one hand, it is certain that governments of these towns have been motivated by local goals of economic development to pursue their strategy of supply augmentation for addressing water scarcity. To that end, it is clear that local priorities have dictated policy/planning in Dharamshala and Leh in the area of water management, and this is consistent with the observation that economic development can be a powerful driver of action in cities. However, policy and planning, as guided by this priority, have not led to sustainable solutions to water scarcity, or explicit climate adaptation strategies. In other words, economic development has certainly been a driver of action in the two towns, but not in a positive way.

A possible explanation for the continued depletion of water resources in the name of economic development in Dharamshala and Leh is that the present structure of economic incentives is shortsighted. In Leh, for example, the current policies of the Leh Development Authority indirectly subsidize excessive consumption of water as a result of the financial assistance they offer to new hotel construction projects. While the expansion in the tourism sector in Leh contributes to the local economy, it ignores long-term impacts on local water resources. In Dharamshala, the perception of water scarcity is weak to begin with, since it is not a perennial concern like it is in Leh. Given this lower level of alarm about the future of water resources, the goals of economic development in Dharamshala seem to dominate any concerns that might be raised about water scarcity in the town. Thus, in both towns, short-term economic benefits outweigh environmental concerns, and consequently, it follows from this trend, that conservation of water resources is viewed as an impediment to economic development in both towns.

Climate change adds a new dimension to the assumptions behind continued economic development activities in both towns. Some locals are claiming that water resources in both towns are plentiful and will continue to meet a growing demand for the years to come (Arya 2009). However, climate change threatens to invalidate this assumption, as it impacts water supply sources, and this possibility is being overlooked in both towns. This implies that even if water management in Dharamshala and Leh were more sustainable than it is now, in the absence of climate change considerations, the efforts to improve water management in both towns will not be as effective. Therefore, it may be argued that there is a need for the incorporation of climate change considerations in the planning processes of Dharamshala and Leh. In fact, some theories on climate adaptation state that climate change considerations can help mitigate the traditional tensions between economic development and the general notion of environmental protection (Roberts 2008). This theory is based on the premise that raising awareness about climate change impacts helps decision-makers understand the long-term implications of short-term decisions. As a result, they learn to recognize that environmental protection measures (e.g. adaptation or water conservation) are "essential underpinnings" of development (Roberts 2008). This implies that accounting for climate change impacts and efforts to manage increasing water demand can reinforce each other as far as making a linkage between environmental protection and economic development is concerned. However, that linkage is still missing in both Dharamshala and Leh.

The absence of climate change considerations in the planning processes of the governments of Leh and Dharamshala, and the limited ability of economic development to induce a progressive, holistic, and anticipatory form of adaptation measures indicates the presence of significant barriers preventing both towns from attaining sustainable solutions to water scarcity. The following section presents a discussion on technological, structural, financial, and political barriers to considerations of climate change in shaping local planning and policies, and barriers to progressive forms of adaptation beyond what is currently taking place in the two towns in the area of water management.

Gaps between Science and Policy

The reliability of the sets of data that Dharamshala and Leh have on climate parameters or discharge in the supply sources is questionable. For example, in the data provided by IPH on the dry period discharge in the supply sources of Dharamshala between the years 1999-2003 (Figure 8), numerous questions were raised about the types and number of sources included in this data set. Additionally, the usefulness of this data in ascertaining the magnitude of the decrease in discharge during the dry season was limited, as it was not complemented with discharge data during the wet season. Moreover, the data on discharge in supply sources that has been generated to date has not been linked to the quantity of snow-cover on the Dhauladhar Mountains, and according to the chief engineer at IPH, the reason for this is that IPH does not have access to data on snow-pack in the high-altitude Dhauladhar Mountains, nor the means to collect it on its own (Tandon 2009). Similarly, there isn't adequate information to make estimates of the quantity of groundwater extracted per day by various users in Dharamshala, as not all pumping wells are monitored (See the section on "Groundwater" and Table 6 in Chapter 5).

Leh has similar gaps in data on the behavior of the supply sources as well as data on the snow-cover from the Khardungla glacier that feeds these supply sources.

For example, even though PHE has made rough estimates of the extent to which certain spring sources in Leh have dried up, accurate quantification of this reduced capacity is not available. Similarly, there have been observations that tube-wells in some areas of Leh are serving at lower capacity (Kaul 2009), but once again, the magnitude of the decline in the groundwater table that has led to this reduced productivity of tube-wells has not been studied (See section on Evidence of Climatic Changes and Shrinking Water-Supply in Chapter 6).

Thus, it is reasonable to conclude that neither Leh nor Dharamshala have reliable, long-term scientific data on changes in climate parameters and hydrological impacts as they make decisions about the future of water supply. In particular, there is very little quantitative data to support anecdotal information about the decreases in the volume of snow-pack on the Dhauladhar Mountains and the Khardungla Glacier. In general, literature on glacial systems shows that there are substantial gaps in the science of climate change and its effects on Himalayan glacial and hydrological systems (Eriksson, et al. 2009). Few climate models have attempted to simulate impacts of climate change in the Himalayas, because the current spatial resolution of models is not sufficiently strong to adequately represent and accurately predict climatic responses. As a result, very few studies of the behavior of snow-pack, glaciers, and permafrost have been carried out in this region, and are spatially and temporally scattered. Moreover, very little long-term monitoring of climatic variables, perennial snow/ice, runoff, and hydrology has been done. Generally, climate models employ extrapolation techniques from data available at comparatively low-altitude areas or parts of the world that have been studied more in depth (Eriksson, et al. 2009). However, given the immense heterogeneity of Himalayan topography, large differences in temperature and precipitation patterns are observed over very short distances, and therefore, extrapolation is not an appropriate tool for predicting climate change impacts (Eriksson, et al. 2009).

All of these factors lead to the conclusion that local governments like Dharamshala and Leh cannot benefit from existing research on glacial and hydrological changes in the Himalayas, and do not have the resources to conduct such research on their own. Additionally, there are many imperfections found in the limited data on available source discharge that the towns currently have. This lack of research, along with the gaps in the data collected by Dharamshala and Leh at the local level, make the formulation of science-based policy in towns like Dharamshala and Leh extremely difficult.

Gaps between Policy and Enforcement

Even for policies on water management that have been instituted, their translation into enforcement on the ground has been lax in both Dharamshala and Leh. For example, there is a large discrepancy between what is prescribed in the Himachal Pradesh Water Policy or Groundwater Act, and the extent to which it is enacted in Dharamshala (See section on "Institutional Structure of Water Management" in Chapter 5). Even though the Groundwater Act mandates that groundwater extraction is supposed to be monitored carefully in Dharamshala, there are practically no records of the quantity of groundwater extracted by users in Dharamshala on a daily basis (See section on "Groundwater" in Chapter 5). Similarly, the State Water Policy encourages a holistic view of water management that includes conservation and demand management: two approaches that have been completely neglected in Dharamshala. In the case of Leh, given that there is no policy guiding the management of water in the town, the objectives of the water agencies are narrowly defined to begin with and any discourse on conservation or demand management is therefore completely absent (See section on "Institutional Management of Water" in Chapter 6). These factors highlight that the existence of a guiding policy is necessary but not sufficient in ensuring sustainable local management of water resources. It must be accompanied by effective enforcement mechanisms at the local level to realize its potential.

Approach of Water Agencies

As mentioned earlier, both PHE and IPH tend to approach the issue of water scarcity as a supply problem with a supply solution. Neither agency has explicitly considered the adoption of other aspects of water management such as conservation, storm-water management, and wastewater management, and how these aspects may help close the gap between water supply and demand. Representatives of both agencies have stated that their primary responsibility is to supply water to their towns (Kaul 2009 and Tandon 2009) and this, along with the technocratic work-culture in the two agencies explains why their only solution to water scarcity has been to look for more sources of supply. This narrow approach to addressing water scarcity is likely to be a significant barrier in ensuring a sustainable supply of water to both towns, given the rate at which these towns are urbanizing, and that at which water sources are drying up (thereby making supply augmentation a non-viable long-term option).

The constricted outlook of the two agencies also results in a lack of communication and coordination with other departments of their local governments for matters related to water use. This is a significant barrier, given that there are many sectors or departments within the local governments of the two towns that affect water consumption. For example, the Leh Development Authority, through its policies on hotel construction, will likely have a significant influence on the future water consumption in Leh, as the commercial sector is the greatest consumer of water in this town. Yet, PHE does not seem to have initiated dialogue with the Leh Development Authority to discuss possible ways of keeping the water consumption of hotels in check (Kaul 2009). Similarly, IPH in Dharamshala has not approached academic institutions like the Government College, Dharamshala (Dhar 2009) for potential scientific information that might help this agency make better decisions about Dharamshala's water supply. Thus, limited scope of the water agencies in both towns leaves them to make decisions on water supply on their own, in the absence of input from other sectors that will impact water resources in the towns in the future.

Financial Constraints

Water management agencies in both Dharamshala and Leh face perennial financial constraints, and are largely dependent upon Central and State Government funding for large-scale infrastructure projects. This is attributed to the fact that recovery of water production costs in both towns is inadequate as water supply is subsidized in both towns.

As shown in Chapter 5, IPH enforced a fixed-tariff pricing structure in Dharamshala, from the years 1993 until 2005, which was later discarded in favor of a consumption-based pricing structure. The consumption-based pricing structure is currently in use, and it is estimated that under this structure, approximately 30% of water production costs are likely recovered from the domestic sector, and 60% of costs are likely recovered from the commercial sector, under the assumption that water production costs in Dharamshala are approximately the same as the national average water production cost in urban areas (See section on "Institutional Structure of Water Management" in Chapter 5). Interestingly, these statistics appear favorable compared to national averages of cost recovery across urban areas in India, as it is estimated that on average, only 10% of the operating and maintenance cost for water is typically recovered from the domestic sector in urban India (Raghupati, et al. 2002). Thus, it would seem that compared to the national average, IPH in Dharamshala is recovering a larger proportion of the cost of water supply. Nonetheless, the agency is undoubtedly cash-strapped, and the inefficacy of water subsidies in providing relief to those who need it indicates that these resources could be better spent in the improvement of urban water services in the town.

In Leh, the fixed-tariff pricing structure continues to be used to date (as shown in section on "Institutional Management of Water" in Chapter 6). Tariffs in Leh are much higher compared to those under the fixed-tariff pricing structure used in Dharamshala prior to 2005. However, the structure of subsidization and their consequences in terms of which sectors benefit the most from subsidies are different from those of Dharamshala. It is estimated that that commercial users (hotels and guest-houses) are the largest consumers of water in Leh, and at the individual level, residents consume significantly lower amounts of water compared to tourists.

Based on these trends, it appears that commercial users are reaping the greatest benefits of subsided water. Those from the domestic sector who do not have access to private water connections do not pay the monthly consumption fee of Rs. 360. But clearly, their use of water is minimal as they have to manage with the amount of water they can acquire from shared PSPs. On the other hand, owners of guest-houses have been known to register their business under the domestic user category and are therefore charged only Rs. 360 per month for water connection and supply, when it is obvious that their use of water is significantly higher than regular home-owners or residents of Leh (as shown in section on "Institutional Management of Water" in Chapter 6). Additionally, it is estimated by PHE that approximately 20-

30% of water supplied to the town of Leh is used for urban agricultural purposes (Kaul 2009). It is reasonable to assume that this use of potable water for agricultural purposes is practiced by users with personal connections. Thus, these are some examples of how lower monthly connection fees for the domestic sector are being abused by the commercial sector. Lastly, as seen in the Chapter 6, pro-tourism policies formulated by the Leh Development Authority in Leh have been indirectly encouraging additional extraction of water as a result of the financial incentives they offer for the construction of new hotels. Thus, as a result of these forms of subsidization in Dharamshala and Leh, neither town's water management agency is in a financial position strong enough to take on progressive adaptation projects in response to water shortage challenges arising in both towns.

Lack of Data, Monitoring Systems and other Technological Resources

Neither Dharamshala nor Leh has reliable, long-term data (spatial, qualitative, or quantitative) on natural parameters such as temperature, precipitation (rainfall and snowfall), stream discharge, or groundwater resources based on which changes in climatic trends can be inferred or future trends projected. Similarly, monitoring systems for regulation of urban water supply are for the most part absent. For example, there are no systems in place to estimate the amount of groundwater extracted from either town on a daily basis in either town. In Dharamshala, although metering is mandatory (Malhotra 2009), by no means has it been enforced throughout the town. Studies on the water consumption patterns of different sectors in Leh or Dharamshala are few and far between. Additionally, storage of data from existing studies is not optimal. The transition to the usage of electronic databases for collecting information has been extremely slow. For example, although management staff in both PHE and IPH has access to technology such as computers and the internet, these facilities have not been embraced willingly by the management. Engineers at IPH expressed their lack of comfort with the use of computers for their daily work (Tandon 2009).

Additionally, gap analysis studies to determine the quantity of water that is unaccounted for have not been conducted. As a result, there is continued ignorance about the lack of efficiency of water services provided in both towns, a significant oversight, given that water losses due to leakages in these towns are estimated to be as high as 25 – 50% (Sterkele 2003). Periodic monitoring of infrastructure to prevent damage and leakages is lax and consequently, there is tremendous wastage of water via leaking pipes and tankers. Finally, the processes for determining water tariffs, allocations of water supply, or planning of new water-resource development projects are not transparent, leading to confusion and mistrust over the means by which decisions are made. For example, it had been stated by a representative of the LAHDC that information about the study done by Tetra Tech on the future of Leh's water management would be made available to the public (Dorjay 2009). Yet, environmental organizations like LEDeG, which are looking to initiate research on urban water issues in Leh, were unaware of the existence of this study (Ete 2009).

Thus, it is concluded that lack of information or data can be crippling if long-term decisions are to be made based on current information and this factor is arguably one of the biggest barriers to improvements in the adaptive responses of Dharamshala and Leh to water shortages.

Conflict between Environmental Protection and Economic Development

The history of Dharamshala and Leh is testament to observations made by social scientists that remote, isolated societies tend to develop socio-cultural and economic institutions in accordance with their environment. These societies have evolved through an intimate relationship with nature and the creation of a unique socio-economic structure adapted to prevailing environmental conditions (H. Singh 1998). For example, subsistence agriculture and bartering used to be prevailing practices of trade in Ladakh, the region in which Leh is located. Similarly, the State of Himachal Pradesh has been described by scholars as an environmentally balanced region, where people lived in harmony with nature (Rajwant 2005). However, history has shown that conflicts arise when societies like those in Leh or Dharamshala are exposed to outside influences and modern development. The dilemma enabling rapid socio-economic development and simultaneously exercising concern for protecting culture and the environment is being faced particularly by economically backward areas facing rapid economic change (H. Singh 1998). Questions are raised over whether it is fair to deny societies the opportunity to benefit from modern development at the risk of adverse impacts such as environmental degradation, or devaluation of tradition (H. Singh 1998).

The influence of the military in Ladakh after 1960s, followed by the introduction of the tourism industry in 1970s made it possible for Ladakhis to adopt a cash economy that was previously unfeasible (H. Singh 1998). Similarly, the recognition of Dharamshala as place of cultural, natural and religious significance in the 1960s created opportunities for the tourism industry that were not available before (Reddy 2008). These socio-economic changes have impacted both towns in many ways. In Ladakh, for example, during the 1960s, locals found employment opportunities offered by the military, and benefited from extended military services such as medical facilities and imported commodities like food grains (H. Singh 1998). Subsistence agriculture gave way to commercial agriculture, since food products were now imported, and the production of vegetables and fruits began to dominate agricultural practices as a result of demand, increasing the wages of agricultural workers by 225% from 1971-81. After 1974, new markets catering to the needs of tourists began to emerge. By this time, Ladakh had transitioned to a cash economy. Job opportunities were created in government offices, schools, hotels, restaurants, and tourism agencies (H. Singh 1998).

Similarly, the designation of Dharamshala as a refuge for the Dalai Lama and the exiled Tibetan community has given rise to a vibrant tourism industry. This has led to investment in infrastructure such as roads, sanitation, hotels, restaurants, and shops which did not exist prior to the 1960s (Tandon 2009). For example, a chief engineer in IPH stated based on his personal experience, that despite the challenges faced by water agencies like IPH in Indian towns, there is no doubt that access to water has improved (Tandon 2009), indicating an improvement in the standard of living in the Dharamshala in the last few decades. Lastly, these socio-economic changes in Dharamshala are influencing surrounding areas as well. Villages near Dharamshala are experiencing a spill-over effect of the tourism industry in the town, with the present generation opting for the tourism service sector by setting up travel agencies, restaurants, and guest houses instead of practicing agriculture[25].

It can be argued that these reforms have benefited Dharamshala and Leh, as evaluated by indicators of economic development such as population growth[26], literacy (male and female), percent non-agricultural workforce, and health improvements (H. Singh 1998). However, development has come at the cost of natural resource depletion, environmental degradation, and a perceived decline in old traditions. Naturally, this has generated numerous debates on whether development in

[25] These findings are based on informal interviews conducted with travel agents and owners of guest-houses.

[26] Population growth was considered as an indicator of economic development as both towns are in relatively remote locations, and used to have a very small population before they acquired cultural and political significance.

regions such as Dharamshala and Leh should mimic that in the developed world. Opinions of scholars from India on this issue differ considerably from those of scholars from the developed world. The general philosophy about economic development in India is that no culture, however remote, remains static and therefore, the importance and relevance of culture needs to be considered in a larger context (H. Singh 1998). Literature on the significance of culture and traditions in remote societies suggests that many cultural elements of societies have outlived their relevance in the modern era, and therefore, recreating the earlier basis of society is not desirable. Advocates of economic development are of the opinion that decisions about the future of development in towns like Dharamshala and Leh should based on the preferences of their constituents, with modern economic development as one option that they could choose from (H. Singh 1998). Indeed, informal interviews conducted with some business owners in Dharamshala and Leh indicated that younger generations in both towns would like to explore sectors other than agriculture, and are demanding amenities such as better transportation, hospitals, energy, and education

In light of these demands, the predominant sentiment in India is that there is a need to maximize the positive aspects of socio-economic development because economically backward areas are entitled to a certain level of modern amenities, and sentiment is reflected in Dharamshala and Leh. Consequently, given the present structure of incentives for economic development in Dharamshala and Leh (as evidenced by the pro-tourism policies in both towns and their implications on water use, for example), and a lack of recognition of the fact that environmental integrity is crucial to continued economic development, the prioritization of environmental protection (and consequently, the preservation of water resources as a means of adaptation to water stress) under the present structure of economic development seems unlikely in Leh or Dharamshala.

Politics of Addressing Climate Change

Climate change and the various controversies surrounding it add a new dimension to the existing conflicts over whether environmental protection (e.g. water resource conservation) should take precedence over economic development in Dharamshala and Leh. In general, literature has shown that the politics of climate change, particularly with regard to who is responsible for causing it, who is suffering from its impacts, who is responsible for mitigating it, how one can adapt to it, and who will finance adaptation, contributes to the paralysis of efforts to address its adverse impacts. In the case of India, the stance of the national government on the issue of addressing climate change has been one that emphasizes the priority of maintaining high economic growth-rates to raise living standards. For example, India's National Action Plan on Climate Change (NAPCC) states that the government will take measures that promote the nation's development objectives while simultaneously yielding co-benefits for addressing climate change effectively (Prime Minister's Council on Climate Change 2008). Additionally, the national government has consistently invoked the principle of common but differentiated responsibility among the international community for mitigation as well as for financing adaptation efforts in India. The NAPCC explicitly states that the measures taken by the Indian government to address climate change would be more successful with assistance from developed countries (Prime Minister's Council on Climate Change 2008).

As for the need to consider adaptation efforts in regions such as the Himalayas, it appears that the government is unwilling to plan and implement drastic measures without sufficient scientific evidence of the impacts of climate change on this mountainous ecosystem. According to the NAPCC, the government has declared that one of the first steps courses of action should be to determine "whether and the extent to which the Himalayan glaciers are in recession" (Prime Minister's Council on Climate Change 2008). This plan states that an observational and monitoring network for the Himalayan environment will be established to assess freshwater resources and health of the ecosystem. From this evidence it is obvious that proposed action to enable adapt to climate change in the Himalayas is in its infancy, and is unlikely to make substantial progress in the immediate future.

Thus, under a national regime that is strategically opposed to encouraging any dialogue on climate change which may oblige the nation to reconsider its goals and means of economic development, local governments such as those of Dharamshala and Leh do not seem to sense urgency in the need for any action in response to climate change. In other words, there is no external pressure to initiate action on climate change adaptation at least from within the nation, which, literature suggests, can be a potential driver of action (Sippel, et al. 2009). If the urgency of the need for action is not being conveyed from the top to the bottom, there is no support base or framework for Dharamshala and Leh to initiate research on climate change impacts or action on climate change adaptation. For example, an academician in Dharamshala and his peers pointed out in an interview that studies of glacial systems require substantial resources, and in the absence of a dedicated framework that makes available funding for research, these studies are carried out sporadically at best and therefore, there is little information on the basis of which decisions on climate adaptation can be made (Dhar 2009 and Deota 2009).

To add to the complexity of climate change politics, there is a vocal contingency of climate change skeptics among the scientific community of India, which is in disagreement over whether climate change is natural or anthropogenic, and whether the changes in the behavior of Himalayan hydrology are as extreme as is predicted by international climate science community. For example, in an interview conducted with an independent consultant who has worked in Ladakh in the past, the consultant stated that in most cases of emerging water scarcity in places such as Leh or Dharamshala, the changes in hydrological systems (e.g. reduced discharge of rivers or streams) are a consequence of over-extraction of water for economic activities, and not climate change (Arya 2009). In other words, these experts claim that the supply of water from these sources is not reducing (at least not at a rate that is alarming); rather it is increasing demand that is leading to water shortage in the urban centers that rely on these hydrological systems. This argument completely negates the need for any dialogue on climate adaptation, and instead shifts the focus on the need to find ways to meet the increasing demand for water. Unfortunately, the measures to meet demand for water have so far only involved exploration and exploitation of new sources of water such as groundwater in both towns. For example, in Leh, the primary recommendation made by Tetra Tech to LAHDC in its report on water management in Leh was the installation of new tube-wells in parts of Leh that were determined to have good groundwater potential (See section on "Efforts to Address Supply-Demand Gap" in Chapter 5). Similarly, in Dharamshala, streams and springs (which have been traditional sources of water supply in the town) are now being augmented by wells, such as the one installed in Dadi (See section on "Efforts to Address Supply-Demand Gap" in Chapter 5).

Summary

This chapter concludes that economic development goals have been the primary driver of action taken by the governments of Leh and Dharamshala to address water scarcity. Climate change considerations have been largely absent from decision-making processes on finding solutions to water scarcity. Additionally, the economic development has not occurred in an environmentally sustainable manner, resulting in a local economy that has failed to recognize that the development of Dharamshala and Leh depends on the integrity of its natural resources like water. This has resulted in the exploitation of water resources of both towns in pursuit of short-term profitability. The failure to take into account climate change impacts in the future water resources planning of the two towns, along with the inefficacy of development goals to drive sustainable use of water is attributed to a number of technological, structural, financial, and political barriers. Taking these barriers into consideration, the next chapter presents recommendations that might enable the towns of Dharamshala and Leh to plan and implement a more progressive, holistic, and anticipatory form of adaptation to water scarcity.

Chapter 8: Recommendations and Conclusion

Previous chapters have shown the impacts on water resources of Dharamshala and Leh as a result of increasing demand as well as decreasing supply of water. Patterns of responses emerging in both towns to address water scarcity reveal the causal factors that have led the towns to the paths they have chosen. This analysis has shown that responses to water scarcity are occurring in scattered forms at various sub-local scales such as the individual/household scale, community scale, and at the town division scale.

Adaptive responses at the individual level in both towns have been reactive, in that individuals reduce the consumption of water at home during periods of acute scarcity, and resume normal consumption habits when water is more readily available. For example, an interview with a household in a low-income neighborhood of Dharamshala revealed an experience of water scarcity at its extreme, as members of the household revealed that in the dry season, they do not take a proper bath for weeks at a stretch, and limit their use of water to drinking and cooking (Dharamshala-Resident 2009). Similarly, in Leh, household interviews show that the residents of Leh understand the importance of conserving water, and are able to restrict their use of water to surprisingly low amounts at times of water scarcity (Leh-Resident 2009).

At the community level, although there has been some effort from community organizations to build the capacity of communities to cope with fluctuations in water supply, most of it has occurred in rural and peri-urban areas, and has been too disintegrated to show substantial benefits at larger scales. Moreover, evidence of participation by community organizations in the area of water management was only found in Leh, and not in Dharamshala.

Lastly, strategies to address water-scarcity at the town-division level have also been primarily reactive as agencies responsible for water services have continuously tried to meet growing demand by tapping new sources with little focus on conservation. Thus, responses at the largest scale considered in this thesis, i.e. the town-division scale, are not part of a coordinated effort to address climate change explicitly, but more representative of efforts to cope with water scarcity as a problem in isolation, for which the only type of solution considered to date is supply augmentation. While climate change is not the only factor contributing to fluctuations in the water supply of these two towns (economic development and population growth are other factors increasing stresses on water resources, which, according to some experts, are more significant than climate change), it is nonetheless an important factor that should not be ignored. The patterns of responses to water scarcity emerging in Dharamshala and Leh, i.e. the absence of dialogue on climate change impacts or consideration of a more progressive, holistic, and anticipatory adaptation approach to water scarcity have been attributed to a number of factors which act as barriers to these dialogues, such as lack of credible scientific data and monitoring systems, lack of financial, technical, and institutional resources, lack of law-enforcement, conflicts between economic development and environmental conservation, and national politics surrounding climate change.

In light of the impacts that Dharamshala and Leh have faced as a result of climate change and economic development on their water resources, and the barriers prevalent in both towns to more climate-centric, progressive, holistic, and anticipatory forms of adaptive planning, this chapter presents recommendations that Dharamshala and Leh may deem beneficial in their efforts to find sustainable solutions to water scarcity.

Scale of Operation

Literature on climate change adaptation seems to suggest an emerging consensus that planning and implementation of adaptation to impacts such as water scarcity should occur at the town scale (See section on "Key Stakeholders that have and can Spearhead Adaptation" in Chapter 2). City and municipal governments generally have the primary responsibility for a wide range of infrastructure and service provision that is essential for good living standards, livelihoods and the reduction of vulnerability to environmental hazards. For example, they are responsible for the provision of water, sanitation, drainage and solid waste collection; for schools and healthcare facilities; and for fire and other emergency services (Dodman, et al. 2008). It follows that the municipal councils of Dharamshala and Leh have the responsibility of providing these aforementioned services to their constituents. As far as the specific responsibility of water services is concerned, it is obvious that these services must correspond with the future demand for water in various sectors in the two towns. At the same time, local governments have the authority to influence the demand for water in various sectors via policy and planning decisions. One possible way to exercise this influence is for municipal governments to act as primary facilitators among the sectors that affect the demand for water in the two towns and create awareness among sectors of their impacts on local water resources (See section on "Key Stakeholders that have and can Spearhead Adaptation" in Chapter 2). For example, LAHDC in Leh could collaborate with the Leh Development Authority to create incentives for water conservation such that entrepreneurs seeking government subsidies for new hotel construction projects are required to incorporate explicit water conservation measures in their project proposals. Similarly, the local government in Dharamshala could engage departments such as the Himachal Pradesh Tourism Development Corporation to encourage these departments to advertise hotels that are contentious in their use of water resources. In terms of identifying a lead agency to oversee adaptation related to water resource management, it seems only natural that agencies in charge of water management (i.e. IPH in Dharamshala and PHE in Leh) be designated as implementing agencies at the town level to act as facilitators in the process of initiating wide-wide adaptation planning in response to water scarcity.

Among the pivotal roles and responsibilities of the local government, an important responsibility that deserves to be mentioned, particularly in the context of Dharamshala and Leh, is fair allocation of water resources among different sectors in these towns. Politics seems to play a major role in how water is distributed among the two towns' constituents. For example, it has been mentioned previously, that in Leh, the tourist industry continues to be indirectly subsidized by the local government despite observations that hotels are among the major consumers of water resources in the town (See section on "Institutional Management of Water" in Chapter 6). The daily per capita water consumption of local households is significantly lower than that of tourists in Leh. Similarly, informal surveys in various parts of the town of Dharamshala indicated that there was great disparity in the frequency and amount of water supplied to lower income versus higher income neighborhoods. The non-uniformity of water supply among various sectors is testament to the fact that the current water supply services are simply not competent enough for all sectors to avail of an adequate water supply. Thus, it is argued that the realities of natural resource constraints in Dharamshala and Leh do not afford these regions the luxury to mimic the path of conventional economic development which has been taken in the first world. Interestingly, local residents do seem to understand this reality, and adjust their water consumption habits accordingly. For example, in Dharamshala, one resident's response to questions on perceptions of water scarcity in Dharamshala was that even though the town receives abundant rainfall, it is of no use if the rainfall cannot be captured effectively (Dharamshala-Resident 2009), and therefore, it is imperative that locals learn to live within the constraints of nature. Similarly, in an interview with a local business owner in Leh, the business owner expressed surprise at the habits of visitors in Leh, and their "need" to take a bath every day (Leh-Resident 2009). He went on to say that dry, cold climate in Leh negates the need for daily baths, and tourists should understand that. It appears that this local conscientiousness needs to be institutionalized in governmental planning. Given the deteriorating viability of the sources of water supply in both towns, it appears that Dharamshala and Leh are approaching a stage where further degradation of their water resources cannot be justified in the name of economic development, especially if damage to water resources threatens the basic survival needs of locals (like drinking water requirements). Thus, one possible adaptation strategy for the water agencies in the local governments of Dharamshala and Leh might be to undertake a re-thinking of priorities for allocation of water resources within the towns.

Support from Other Stakeholders

In addition to the special role of local governments, it is necessary to recognize the potential roles of other sectors in the planning and implementation processes of responses to water scarcity in Dharamshala and Leh. Literature has shown that planning and implementation of adaptation involves a broad range of sectors such as multi-level government agencies, civil society organizations, the private sector, academia, think tanks, research institutions and citizens (Center for Science in the Earth System 2007).

Among possible interactions between local governments and these sectors, the amount of multilevel government interaction has been cited as an important indicator of success in adaptation planning processes (Katich 2009). Based on these observations, it can be argued that higher levels of governance, such as the State (Himachal Pradesh and Jammu & Kashmir) and the Central Governments of India will play an integral role in providing financial, technical, and institutional resources required for adaptation and therefore, collaboration with higher levels of government should be maximized. Within the local government structure of Dharamshala and Leh, the departments that influence patterns of water use in the two towns should be identified, and there needs to be better communication and coordination of goals, policies, and activities among the local water supply agencies and these other departments. For example, in Dharamshala, there is potential for dialogue on water-management among IPH and other departments such as Urban Development, Town & County Planning, Tourism, and Environment, Science & Technology. Similarly, the Leh Development Authority, along with the Departments of Planning, Social Welfare, Power, and Roads & Buildings are some of the divisions in Leh that most likely influence the way water is distributed within Leh. It is recommended that these departments work together towards a common goal of securing the future of water in Leh.

In addition to the government, the potential of the civil-society sector (in Leh, especially) must also be mentioned, particularly in light of their historic involvement in environmental issues. In Leh, for example, organizations like LEDeG, LEHO, DIHAR, and LNP have been actively involved in water-related issues in the region of Ladakh, albeit in rural areas (See section on "Other Efforts on Adaptive Management of Water Scarcity in Leh" in Chapter 6). Nonetheless, their experience can be applied to urban Leh. In Dharamshala, while the civil society sector was not explicitly identified as being involved in water management, it is very likely that there are local non-profit organizations invested in local socio-environmental issues (Dhar 2009). From rural Ladakh's experience, it can be argued that there is potential value in learning from and applying methodologies used by local community organizations in order to build the capacity of vulnerable population groups, particularly methodologies related to risk assessment, stakeholder inclusion, and brainstorming of solutions. Given the limited number of studies on community-based adaptation in literature, there isn't strong evidence that project-level adaptation can be scaled up to the town level (See section on "Current Status of Adaptation to Climate Change" in Chapter 2). Nonetheless, there is some value to these efforts, as they can be used as a starting point. Project outcomes can provide substantive lessons on adaptive practices. Dissemination of lessons learned, and public education/outreach initiatives can be a step towards replication of adaptation efforts at the municipality scale (The World Bank 2008).

Lastly, research organizations such as DIHAR in Leh, or academic institutions such as Government College, Dharamshala, will likely play a crucial role in closing the gap between the science and policy of climate change and water resources. They can also potentially contribute to the development of concrete adaptation measures on the ground, particularly those that involve dissemination of technology. For example, DIHAR has conducted research on climate resistant varieties of crops and vegetables and sustainable agricultural practices that minimize the use of water. DIHAR's research strongly suggests that drip irrigation and mulching are extremely effective mechanisms of conserving water in Leh's climate (Stobdan 2009). This research has high pertinence for urban Leh, because there is extensive urban agriculture practiced within the town, which consumes approximately 30% of drinking allotted to the town (Kaul 2009).

Similarly, the Government College has acquired funding to establish a monitoring system to record climate parameters such as snowfall and rainfall pertinent to Dharamshala (Dhar 2009). This information will be useful to IPH in examining trends of changes in the local climate, and their implications for the town's water resources.

Acknowledgement of Climate Change and Mainstreaming into Decision-making

In both Dharamshala and Leh, while there isn't complete ignorance of the fact that sources of water supply of both towns (i.e. snow-pack on the Dhauladhar Mountains and Khardungla Glacier) are shrinking, the water management agencies have not made a formal linkage between this observation and emerging evidence on climate change. Consequently, the adaptive responses in both towns to water scarcity have been limited to tapping of additional sources (without accounting for the possibility that these sources may not be viable as a result of climate change in the future).

Thus, it is recommended that the unavoidable impacts of climate change need to be accounted for in all departments of local governments of Dharamshala and Leh, including the water management divisions. In other words, in addition to just viewing water scarcity as consequence of increasing demand, the fact that water scarcity is also manifested as a result of changes in supply must also be considered along with the reasons for these changes, because climate change threatens to invalidate the current water supply augmentation strategies of both towns. Thus, dialogues on the reality of climate change need to be initiated in the local government along with studies on how each of the sectors in the two localities is affected by climate change.

Additionally, it is important to ensure that climate change does not become a marginalized issue in the local governments of Dharamshala and Leh, as many environmental departments often do. Instead, there must be an effort to integrate assumptions and scenarios of climate change at all levels and departments into the plans, policies, and investment processes of the town governments (Center for Science in the Earth System 2007). For example, in light of climate change, economic development goals must be reconsidered by town divisions in charge of urban development, given their implications for water scarcity. Similarly, divisions responsible for disaster response must consider the possibility of more frequent or intense weather events like droughts as impacts of climate change.

Desirable Characteristics of Water Management Agencies

Given that planning and implementation of urban water supply in Dharamshala and Leh is primarily handled by specific water agencies, namely PHE and IPH, it is these agencies that will have the main responsibilities for decision-making as far as water issues are concerned. Consequently, these agencies must possess certain characteristics that enable them to perform their duties efficiently. These characteristics are described below:

Autonomy

IPH and PHE appear to be crippled by their reliance on higher levels of governance for investments in water infrastructure, or in research/development (See sections on "Institutional Structure of Water Management in Chapter 5 and "Institutional Management of Water in Chapter 6). One of the reasons for this lack of autonomy is that the water agencies do not generate sufficient revenue in order to be able to invest back into their operations and make them more efficient. This is due to the subsidization of water supplied by these agencies. In order to remedy this, reforms are recommended in the tariff policies of both towns.

According to scholars of urban water management, the main purpose of tariffs is to enable recovery of maintenance and operational costs, repay past loans taken to expand/improve infrastructure, and possibly create savings for future investments. But at the same time, tariffs should take into account equity issues and be adjusted according to the capacity of end-users (Whittington 2003).

In general, the introduction of water meters to houses with private connections has been shown to lead to substantial reductions in water demand. Water meters also permit the use of progressive tariffs (either be in the form of volumetric rates or increasing bulk tariffs (IBT)), which can then possibly cross-subsidize users without private connections, provided the revenue from metered connection is sufficiently high (Cairncross, et al. 1993). In Dharamshala, a volumetric tariff rate has already been mandated, and all private connections are supposed to be metered (Malhotra 2009). To this end, the benefits of metering in Dharamshala have been recognized in theory. However, this mandate has not been strictly enforced at the ground level, and many connections continue to operate under the fixed-tariff pricing structure. In Leh, fixed tariffs continue to be the norm and there is presently no plan to adopt a progressive tariff rate (Kaul 2009). Additionally, in both towns, the domestic sector continues to be heavily subsidized compared to the commercial sector. In fact, users of water in Leh seem to be taking advantage of the subsidization of the domestic sector's water supply by using domestic drinking water for commercial purposes such as urban agriculture (Kaul 2009).

In considering alternatives to subsidized water supply, it may be worth looking at case studies in which the domestic sector's water supply is not subsidized. In

Singapore, for example, water supplied to the domestic sector is charged at the same rate as the industrial or commercial sector, with special provisions for low-income groups in the form of rebates or targeted subsidies. In addition to base tariffs, the Singapore government also employs an array of taxes such as a tiered water-conservation tax, a water-borne fee to offset the cost of treating used water and maintaining the sewage system, and a sanitary application fee based on the number of sanitary appliances (toilets) installed in each household/building. All of these pricing mechanisms have helped reduce the demand for water in Singapore considerably (Tortajada 2006). It is recognized that a comparison between a city-state like Singapore and towns like Dharamshala and Leh is not ideal, given their differences of scale and socio-economic conditions. In the context of Indian municipalities, it has been argued that given the magnitude of income disparities within most Indian towns, some degree of subsidization is inevitable (McKenzie, et al. 2009). After all, even Singapore has special provisions to the low income sector in what is otherwise a uniform, subsidy-free water pricing structure. However, according to literature, the assumption that low-income groups cannot meet the real costs of water supply is not always valid. Besides, given that lower income neighborhoods have the least number of individual water-supply connections, subsidies under the fixed-tariff pricing model are not even benefiting the groups they are intended to benefit. In India, it is estimated that 70-80% of subsidies spent on water do not reach the poor (McKenzie 2009). Research has shown that in poorly serviced cities or towns of developing countries, the lowest income groups often end up paying substantial amounts of money (either to alternative water vendors, or in the form of health costs from lack of reliable water supply). Additionally, several studies have concluded that lower-income groups will pay more for water if it is conveniently and reliably supplied

(McKenzie, et al. 2009). Thus, if pricing reforms can improve the quality of water services, there is evidence that the public will be willing to pay for these services and therefore, pricing reforms should be considered in Dharamshala and Leh.

Transparency, Accountability, and Performance

Chapters 5 and 6 have shown that the transparency, accountability, and performance of the water agencies in Dharamshala and Leh have been found to be lacking. For example, based on interviews with local residents (or in the case of Leh, with community organizations), it was sensed that the public had a poor understanding of how the agencies operate as far as provision of water services is concerned. For example, residents didn't necessarily understand how tariffs were set, and information related to the future plans of the agencies was not easily accessible to the public (e.g. the Tetra Tech report on Leh's water supply, or the water demand projection data for Dharamshala).

As far as performance and accountability are concerned, the process for addressing complaints or requests did not appear to be very streamlined in either agency. Visits to the agencies revealed that there would be lines of people waiting to be attended to, and there was a shortage of appropriate, qualified staff members to note town their complaints. It seemed that in both agencies, most queries would pass through one or two junior engineers and as a result, the junior engineers were over-worked compared to the administrative staff. Thus, it is recommended that water agencies in both towns take specific measures to improve their transparency, accountability, and performance. For example, efforts could be made to explain to consumers the various steps involved in providing water services, and how tariffs are set. It would be beneficial if, in addition to technical expertise, the staff of the PHE and IPH possesses some level of proficiency in areas such as accounting and information technology, which are equally important in water provision services. Additionally, the overall performance of the water supply agencies in terms of the quality of their services needs to be improved. For example, the new tariff structure in Dharamshala needs to be properly enforced. Similarly, directives of the Himachal Pradesh Water Policy and Groundwater Act need to be effectively enforced on the ground. In Leh, the misuse of subsidies by the commercial sector needs to be addressed through better regulation of existing and new users of private water connections.

Both agencies could set concrete goals that give incentives to their staff members to improve their performance and services. These goals could be aligned with performance indicators such as efficiency of revenue collection, number of daily complaints resolved, number of areas monitored for leaks, number of areas serviced, or percent reduction in 'unaccounted for' water. These goals can hold the staff accountable and motivate the water agencies to become more efficient.

Holistic approach to water management

Currently, both PHE and IPH manage water supply as a distinct operation from other related departments such as wastewater management and storm-water management (which is more important for Dharamshala than it is for Leh). In fact, even within the range of responsibilities involved in water supply, PHE and IPH do not consider conservation as one of their primary responsibilities. This narrow outlook or perception of their roles and responsibilities has led these two agencies to operate in isolation of other aspects of water management, the inclusion of which could potentially improve water-supply services in the two towns. For example, in Dharamshala, better management of storm-water through capture and storage could mitigate scarcity faced by the town in the dry season. This has been indirectly referred to by academicians in Dharamshala. For example, in an interview with a faculty member at the Government College, Dharamshala, it was pointed out by him that even if Dharamshala were to receive only 50% of its average rainfall, there would still be enough water to last throughout the dry season, provided the existence of rainwater storage infrastructure (Dhar 2009). Similarly, the improvement and promotion of the traditional Ladakhi sanitation system in Leh will go a long way in reducing demand for water, while simultaneously reducing the quantity of wastewater generated. Efforts have been made by organizations like LEDeG to promote traditional Ladakhi toilets in the Leh Community. According to the director of LEDeG, if there was one technical intervention that could be extremely effective in reducing the stress on Leh's water resources, it would be the promotion of Ladakhi toilets (Hasnain 2009).

Information, Education, Communication (IEC) and a Revival of Local Knowledge and Traditions

As part of an effort to bring about reforms in water management in Dharamshala and Leh, the IEC approach is recommended as a key outreach strategy to create awareness among the public about the saliency of water scarcity in the context of climate change and economic development. IEC is defined as a three-pronged approach consisting of information (designed to keep the public informed), education (designed to increase the public's understanding of the issues of concern, and communication (designed to mobilize support for activities) (Sadik 1995).

It is recognized that the 'general public' is comprised of distinct sectors such as the private sector, civil-society sector, the media and the public sector (Center for Science in the Earth System 2007). Depending on the audience, the means and content of public outreach would have to be modified, but overall, outreach should consist of a clear message that describes the changes in water resources that have taken place and/or will take place in the future, the causal factors behind these changes, the need for concerted action to address implications of these changes, and possible courses of action (which would be an iterative process based on stakeholder input). For example, a better understanding of the science of climate change will enable the public to understand the causes behind changes in the local climate (which they already perceive) and therefore comprehend the scale of this challenge. It will also give the public a long-term perspective, and therefore sensitize them to the fact that short-term coping strategies or responses will not necessarily be viable in the long run, and therefore, different adaptation strategies must be employed.

If the audience in the outreach effort is internal (i.e. comprised of government officials), the mode of outreach could be inter-departmental or inter-governmental meetings or seminars. For external audiences (community organizations, the general public, and the private sector), an array of strategies such as dissemination of brochures, publishing of press-releases, public meetings, social events, etc. could be used to achieve IEC goals (Center for Science in the Earth System 2007).

Given the dependence of Dharamshala and Leh's water supply on the natural hydrological cycle, the public, at the individual level, has historically exhibited the need to use water conscientiously. Also, anecdotal evidence shows that the public is generally aware of climatic changes in Leh as well as in Dharamshala, and their implications for water supply (Behera, et al. 2009). In many cases, it is the people without reliable, personalized access to water who are able to uniquely adapt to water shortage because they have experienced it frequently (Leh-Resident 2009 and Dharamshala-Resident 2009). The quantity of water consumed by households "depends on accessibility as determined primarily by distance and time, but also including reliability and potentially cost" (Howard, et al. 2003). It is estimated that compared to households served by public taps, households with personal access to water (single tap) use 2-4 times more water, and households with multiple taps use even more water (Cairncross 1993). Therefore, in times of scarcity, it is the vulnerable populations that are often more resourceful when it comes to coping with extreme consequences.

In fact, the adaptive capacity of individuals has been tested to the fullest in some lower income neighborhoods of Dharamshala and Leh where people consume as low as 20 liters of water per capita per day. Under these circumstances, water is used only for drinking and cooking. Bathing and washing clothes cannot be accommodated every day, and people have to rely on natural springs or streams for these activities at minimum (Leh-Resident 2009 and Dharamshala-Resident 2009). While it is obvious that 20 liters per capita per day does not meet WHO guidelines for sustenance of basic health, it also indicates the extent to which humans can reduce their consumption of water during times of scarcity.

For many years, people in Dharamshala and Leh have adapted to the variability in water supply by means of local knowledge and traditional technologies. Lessons can be learned from this resourcefulness and adaptability of locals, and borrowing from these values, messages of conservation and appreciation for water resources should conveyed across all sectors of the public by the local government.

Role of Technology

Technology (soft and hard) will play a very important role in the implementation of adaptation measures. Adaptation solutions from a technological standpoint can be considered at different scales. For example, adaptation can occur at individual/household level, community level, sector level or municipal level. The following list of technologies is recommended as potentially useful in building the adaptation capacity of Dharamshala and Leh:

Monitoring Systems for Snow-Cover, Surface Water, Groundwater, and Climate Parameters

It has been mentioned that lack of reliable, long-term data on snow-cover, surface water, and groundwater resources, or other climate parameters such as rainfall and temperature in Dharamshala and Leh is a significant barrier to adaptation. Credible, up-to-date scientific knowledge is essential for the development of adaptation policies, and there needs to be at least a preliminary scientific basis for adaptation to water scarcity in Dharamshala and Leh, which will require collaboration with higher orders of government agencies and academia. Thus, monitoring systems possessing the following characteristics are recommended for Dharamshala and Leh:

As far as snow-cover is concerned, past studies have shown that technologies such as remote sensing allow for regular and repeated monitoring of snow-cover (The World Bank 2008). However, this level of monitoring would have to be carried out at the regional scale, via the installation of sensing systems by the National Government. Results on particular glaciers like those of the Dhauladhar Mountains, or the Khardungla region could then be shared with the municipalities such that they may keep track of local climatic changes that affect their water supply. Current literature on remote glacial monitoring suggests that in order to get the most accurate data, monitoring systems should ideally include both ground-based and satellite-based monitoring. Well-equipped stations and long-term monitoring, networking, and cooperation within and outside the region are crucial for this technology to be helpful in enabling adaptation at the local level (Eriksson, et al. 2009). The extent to which these advanced technologies can be installed in an Indian context is debatable. However, financing for this technology may be possible under India's current

NAPCC, which has provisions to determine "whether and the extent to which Himalayan glaciers are in recession" (Prime Minister's Council on Climate Change 2008).

As far as monitoring of discharge in the supply sources of the two towns is concerned, it appears that Dharamshala has some data on normal average discharge, lean period discharge, and the extent to which discharge in current supply sources has reduced in the last ten years. Leh, on the other hand, has no data on normal or lean period discharge, and only some preliminary estimates on the extent to which the capacity of current supply sources like tube-wells has reduced. In general, from Chapters 5 and 6, it can be said that there are large gaps in this data, and as a result, it is not as useful as it could be in helping the agencies better understand the reasons behind the variability in discharge, and modify their strategies accordingly.

Therefore, it is recommended that both agencies conduct continual monitoring of the discharge in all supply sources to be able to detect long-term changes in discharge, and correlate these changes with climate change or over-extraction.

In addition to discharge data, information on climate parameters like rainfall and temperature needs to be collected and stored in one location such that trends in these parameters are easy to identify. For example, it was noticed that in IPH, data is being collected on rainfall and temperature, but it is not stored electronically, and therefore, performing statistical analyses to identify possible changes in rainfall and temperature is not convenient. In Leh, PHE did not have access to daily temperature or precipitation data (snowfall or rainfall, although rainfall is less relevant to Leh given that it receives very little rain). However, it was noticed that there was a weather station on DIHAR's campus, which collected information on temperature. In the future, this information could possibly be shared with departments of the LAHDC, or LAHDC could install a weather station of its own so that any possible changes in the local climate can be identified.

Lastly, both towns need to improve their regulatory monitoring systems, particularly for groundwater resources. This is important, given that groundwater is being promoted as the key to closing the gap between the supply and demand for water in both towns. In the absence of monitoring systems that regulate the extraction of groundwater resources, the future viability of groundwater resources cannot be assessed, as there is no way to verify if groundwater is being recharged at approximately the same rate as extraction. In order to initiate monitoring of groundwater resource extraction in Dharamshala, the policies prescribed in the Himachal Pradesh Groundwater Act need to be enforced, whereas in Leh, policies regarding sustainable groundwater use need to be formulated as a first step, and then enforced in the various sectors that consume water in the town.

Regional Climate Models

Until now, the Himalayas have not been well represented in global climate models because of resolution deficiencies. In order to be able to predict future impacts of climate change in the Himalayas, regional climate models (RCMs) with a higher resolution than global models need to be constructed for the especially vulnerable regions of the Himalayas. If the results of RCMs are successfully downscaled, they can then be potentially used as inputs in local impact assessments, particularly for watersheds or sub-catchments (Eriksson, et al. 2009). Research at this level of complexity is obviously beyond the scope of local governments of Dharamshala and Leh. However, as mentioned earlier in the section on remote sensing technology, the National Government of India could potentially fund research on regional climate modeling under provisions of the NAPCC.

Storage Systems

Both Dharamshala and Leh lack the storage capacity needed to reduce the inter-seasonal variability in the availability of water. The development of water storage is considered by the IPCC as a key adaptive measure for climate change impacts (Vaidya 2009). It is necessary to consider the potential of natural storage systems (snow, ice, lakes, ponds, groundwater, etc.) in the cryosphere, biosphere, as well as constructed systems (artificial tanks, ponds, reservoirs, etc.). Depending on geophysical conditions, a combination of natural and artificial systems could be employed to increase storage capacity in both towns. For example, ponds and tanks could be constructed to harvest rainwater. To some extent, the merit of storage systems has already been recognized in Leh at the community scale. Under the guidance of community organizations such as LNP and LEHO, artificial glaciers and ponds have been constructed in peri-urban and rural Ladakh to reduce inter-seasonal variability in the availability of water (Norphel 2009). The feasibility of these storage systems for urban Leh needs to be examined. In Dharamshala, the potential for rainwater harvesting at the municipality scale is high, given that the town receives abundant rainfall (Dhar 2009).

Dammed reservoirs might also be a feasible option to collect surface water (from streams or rivers) that would otherwise flow away during the wet season. Additionally, if aquifers have been identified as a source, groundwater recharge could be used as a storage strategy (Vaidya 2009). If natural storage systems are identified for use as storage options, it is necessary to turn them from a passive source to a planned and active source of water storage. Given the scale of natural systems, it is likely that modification of natural systems will affect downstream communities, thereby requiring inter-governmental coordination and agreements. It has been recognized in literature, that in addition to a sound understanding of hydrology, proper institutional mechanisms are also important to increase the water storage capacity of localities (Vaidya 2009), and this applies to Dharamshala and Leh.

Lastly, in addition to large-scale storage at the town or inter-town scale, rainwater harvesting could potentially be practiced at the individual household and community scale. Consumers in both Dharamshala and Leh are familiar with household storage of water, given that municipal supply is restricted to a few hours per day. Rainwater can serve as complementary to piped water, particularly in areas where piped water is not reliable. Rainwater harvesting at the individual household scale has been practiced to some degree by communities without reliable access to water in Dharamshala (Dharamshala-Resident 2009). However, given the physical limits of the extent of possible storage at an individual scale, it not feasible for households to store surplus water on a long-term basis in the wet season and use it in the dry season. Therefore, systems large enough to protect Dharamshala against the inter-seasonal variability in water availability can be conceived only at the town scale.

Leakage Prevention and Reporting Mechanisms

Leakages are a common and significant problem in municipal water supply. It is the inadequate maintenance of piped water networks that results in cracks and leaks, which in turn, cause significant losses of water (McGranahan, et al. 2000). The percentage of 'unaccounted for water', i.e. water lost due to leakages is typically quite high in developing nations. In Dharamshala and Leh, a significant portion of total water supplied is believed to be unaccounted for as a result of leakages as well as negligence shown by the public towards public water sources, failure on field technicians' parts to follow procedures while operating water transport equipment, and lack of maintenance of storage tanks or personal water supply systems (pipes, taps) by consumers (Sterkele, et al. 2003 and Akhtar 2010). The percentage of water lost to these various defects is estimated to be 25-50% in Dharamshala. While this percentage has not been estimated in Leh, past studies show that 'unaccounted for' water in Leh is very high (Akhtar 2010).

In order to remedy this, leakage prevention needs to be prioritized among the responsibilities of water agencies in both towns. Future expansions or modifications to the piped water network should follow adequate construction standards like the use of insulated durable pipes instead of non-insulated galvanized iron or plastic piping (Tetra Tech 2009). Proactive maintenance and repair of existing infrastructure must be carried out on a periodic basis. A mechanism could be created for consumers to report leakages or to the water management agencies by phone or in person. Incentives could be offered to encourage consumers to communicate with water management agencies. Agencies, in turn, could set up performance goals, requiring staff to respond to reports by certain deadlines. Additionally, to discourage negligent behavior and improper use of public water supply sources, positive or negative reinforcement strategies could be used in neighborhoods. For example, neighborhoods that leave public taps running could be fined. Alternatively, leaders in communities could be entrusted with the responsibility of ensuring that the public water supply sources are properly used.

In summary, it is obvious that in both towns, large amounts of water are lost to leakages and to some degree, carelessness. Accounting for these losses will substantially increase the efficiency of the water distribution system in both Leh and Dharamshala, and to some extent, alleviate the scarcity that is manifested at least partially because up to half of the water supplied by agencies is lost during distribution.

Rationing

Currently, both IPH and PHE supply water for a few hours per day. During periods of scarcity, the frequency of water supply is reduced even further. Given the realities of water supply constraints in both towns, it might be a useful demand management strategy to continue the use of rationing even if sustainable solutions are found to the problem of water scarcity in either town. In fact, given that water supply in both Dharamshala and Leh has lagged behind demand for the past 40 years, and that demand has been predicted to increase in both towns, rationing might not be so much a strategy as a necessity in the future.

Promotion of Alternative Sanitation Technologies

The option of alternative sanitation might be more applicable in Leh than in Dharamshala. For many generations, residents in Leh have been using traditional Ladakhi toilets for sanitation purposes. These toilets are similar to eco-san toilets, which rely upon dehydration and decomposition for the destruction of pathogens from human waste (Esrey 1998). Since this form of sanitation is decentralized, it does not require water as a medium for transport of human waste. It is estimated that approximately three-quarters of households in Leh use traditional Ladakhi toilets (Akhtar 2010). In a survey of 100 households conducted by LEDeG, 50% of interviewed households desired a flush toilet. In the commercial sector, a survey of 102 hotels and guest-houses (total) reveals that while 93% of guest houses had traditional Ladakhi toilets, the percentage of hotels with traditional toilets was lower, at 53%. Additionally, it was only the hotel staff that primarily used these toilets, and not the guests. Therefore, the presence of Ladakhi toilets in hotels or guest-houses doesn't automatically imply reduced water use by guests. It is clear that while a large percentage of homes still use Ladakhi toilets, the tourism sector has switched almost exclusively to conventional water-intensive, centralized sanitation systems in order to meet the cultural preferences of foreign tourists. Even within the domestic sector, a preference for centralized sanitation systems has been expressed if there were enough water available.

Therefore, messages conveying the practicality and benefits of traditional toilets need to permeate across Leh, an effort that can be initiated by the PHE with assistance from community organizations such as LEDeG, LEHO and LNP. In the commercial sector, campaigns can be launched to educate tourists about environmental issues facing Leh, and encourage tourists to use traditional toilets during their stay in Leh. Incentives can be provided by the Leh Development Authority to hotel and guest-house owners to include Ladakhi toilets in their offered services.

It has been pointed out by locals that Leh has the optimal climate for ecological sanitation to function properly. The dry air and solar radiation typical to Leh's climate are conducive for rapid decomposition of human waste (Hasnain 2009). Therefore, continued application of this technology in Leh will be a key strategy in managing the water demand in this town, given the amount of water consumed by centralized sanitation systems is substantial.

Ecotourism

Over the years, ecotourism has been promoted and widely adopted as a strategy for funding nature conservation, while at the same time contributing to the socioeconomic development of local communities, and providing for quality tourism experiences (Stone, et al. 2003). In addition to marketing nature conservation, ecotourism also offers opportunities to market local traditions and culture, thereby creating incentives for their preservation (EplerWood International 2005). By definition, eco-tourism should be environmentally and socially responsible and in order to make this possible, the service providers in this industry must adhere to principles of sustainable development in their business.

There are numerous ways in which the principles of eco-tourism could be adopted by the tourism industry in Dharamshala and Leh. In Leh, for example, hotels could introduce guests to the concept of ecological sanitation and offer incentives to guests to use this technology during their stay. In general, in both towns, hotels could make the effort to provide messages of water conservation encouraging guests to use less water.

Additionally, since the tourism industry in both towns is heavily based on nature tourism and outdoor activities such as trekking or biking, efforts could be made to incorporate environmental education into the tour packages offered by travel agencies in these towns. For example, information about the glacial sources of water in Dharamshala and Leh, impacts of climate change on these sources, and their translational effects on water supply could be published by travel agencies in the form of colorful brochures, and guided tours/treks in the Khardungla region or the Dhauladhar Mountains could emphasize the importance of these glacial systems for the survival downstream urban societies to create a meaningful, educational experience for tourists..

It has been observed from studies that the success of ecotourism depends on this industry's ability to generate a wide variety of benefits for a wide variety of stakeholders. However, the more inclusive the scope of ecotourism, the more difficult it is to realize (Stone and Wall 2003). For example, in the context of Leh, hotel owners are wary of the repercussions of exclusively offering traditional Ladakhi toilets to their guests as part of an effort to adopt green practices. On the one hand, they would be playing a role in encouraging water conservation, but on the other hand they may risk a decline in the number of tourists with different cultural preferences.

Nonetheless, ecotourism holds potential in enabling the conservation of water resources in Dharamshala and Leh. Both towns are places of natural, cultural, and spiritual significance, and there is merit to promoting these assets under the banner of ecotourism with the multi-layered objective of protecting the water resources of both towns, and continuing to promote tourism, which is integral to their economy.

Concluding Remarks

Among the existing and projected impacts of climate change, impacts on water resources are expected to exacerbate the current and future threat of global water scarcity. From the regions of the world that will be impacted by water scarcity, glacier-dependent societies are especially vulnerable due to the more pronounced effects of climate change on the glacial systems that regulate the water availability of these societies. In this thesis, water scarcity was examined as an impact of climate change in Dharamshala and Leh, two glacier-dependent towns of northern India, while recognizing that climate change is not the only factor causing depletion of water resources in these towns. In order to show the linkage between climate change and water scarcity in these towns, evidence on the changes in local climate parameters as well as changes hydrology of the water supply sources of the two towns was presented. Consequently, it was shown that water scarcity is clearly not just a demand problem but also a supply problem. In light of the scarcity facing these towns, the measures taken by the local governance institutions to address this issue were identified. It was revealed that the primary form of adaptive responses employed by both towns to manage water shortage has been supply augmentation. The driving forces behind this nature of response have been goals of economic development being pursued by the local government to improve the standard of living of their constituents. However, economic development as a driving force has not been effective in inducing holistic adaptive responses to water scarcity (which include features such as demand management, conservation, education, etc.). Additionally, climate change considerations have been largely absent in the policy/planning processes that govern urban water management in both towns. This leads to the conclusion that the responses of Dharamshala and Leh to water scarcity have been influenced by the pursuit of short-term economic benefits in a local economy that fails to take into account the importance of the integrity of natural resources like water to its survival. This perpetuation of unsustainable economic development and failure to account for climate change in the planning and policy processes of local governments in the area of water management points to the presence of several technological, structural, financial, and political barriers to the planning and implementation of effective climate-centric and holistic strategies for adaptation to water scarcity in Dharamshala and Leh.

This thesis offers a number of recommendations to enable Dharamshala and Leh to overcome these barriers. These recommendations are intended to provide a starting point for the local governments of Dharamshala and Leh (particularly the water agencies) to initiate adaptation to water scarcity resulting from climate change as well as over-extraction. Many of these recommended measures are within the scope of what the water agencies and local governments can achieve, in the absence of assistance from higher orders of government or international aid. This indicates that there is plenty of low-hanging fruit to be picked in the ways to address water scarcity in towns like Dharamshala and Leh, and these opportunities must be taken before some of the more complex measures are considered.

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Appendix A: List of Topics Explored in Fieldwork

The following list contains the broad categories of topics that were researched during fieldwork in Dharamshala and Leh:

- History of water resources management;
- Principal sources of water supply (traditional and current);
- Current and projected demand and supply of water;
- Evidence of the impacts of climate change in terms of water supply (i.e. irregularities in rainfall, snowfall, glacial melting, etc.) and quantification of the magnitude of impacts;
- Perceptions of institutions about water scarcity as an explicit impact of climate change versus over-extraction;
- Evidence of bottom-up or top-down adaptation to water scarcity, either in response to the perceived need for supporting continued economic development, or in the context of addressing a specific impact of climate change;
- Driving forces behind these initiatives (such as the recurrence of acute, short-term and destructive impacts, commitment from key stakeholders, revitalization, conventional economic development), and primary stakeholders involved in spearheading these initiatives;
- Challenges/barriers to coordinated and efficient adaptation;
- Potential for adaptation to water scarcity beyond current initiatives;
- Assessment of the applications for soft as technological and policy-planning solutions, given the different manifestations water scarcity, and accounting for the social and environmental consequences of these technologies.

Appendix B-I: General List of Interview Questions

1) Have you noticed changes in local climatic patterns, such as changes in temperature, rainfall, or snowfall? What do you attribute these changes to?

2) Is water scarcity a salient issue in your department/organization/profession/?

3) For how long has water scarcity been a noticeable impact?

4) How is your organization/department/profession coping with or addressing water scarcity? Have these measures been successful?

5) Why is your organization/department/profession taking this particular approach as opposed to a different approach? What motivated your organization/department/profession to act in this specific manner?

6) What barriers do you/your organization/profession/department recognize to dealing with adaptation to water scarcity?

7) From your experience, are there particular adaptation measures that you've come across that have been successfully implemented in your household/profession/organization/department and might have wider application?

Appendix B-II: List of Questions for Households

1) How much water do you consume on a daily basis?

2) How would you evaluate the level of water services provided by the water agency?

3) Have you noticed patterns or changes in water supplied (e.g. frequency, amount, quality, etc.) as well as changes in your personal demand in the recent past?

4) How do you cope with water shortage when you are faced with it?

5) How do you think water supply to your home/business can be improved?

Appendix C: List of Interviewees

Interviewee	Title	Organization	Interview Date
Dr. Ritesh Arya	Independent Consulant	Arya Associates	August 2009
Mr. Mohammad Deen	Founding Member	LEHO	August 2009
Dr. Sunil Dhar	Professor	Government College, Dharamshala	August 2009
Mr. Chering Dorjay	Chief Executive Counciller	LAHDC	August 2009
Ms. Mibi Ete	Project Manager	LEDeG	August 2009
Mr. Mohammad Hasnain	Director	LEDeG	August 2009
Mr. Dinesh Kapoor	Junior Engineer	IPH	August 2009
Mr. Ravindra Kaul	Executive Engineer	PHE	August 2009
Mr. R.P. Tandon	Chief engineer	IPH	August 2009
Mr. R.K. Malhotra	Superintending engineer	IPH	August 2009
Mr. Chewang Norphel	Retired Civil Engineer	LNP	August 2009
Dr. Tsering Stobdan	Senior Scientist	DIHAR	August 2009
Dr. Harjit Singh	Professor	JNU	August 2009
Dr. Milap Sharma	Professor	JNU	August 2009
Mr. Tashi	Field Engineer	PHE	August 2009