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AFGHANISTAN

# Scoping Strategic Options for Development of the Kabul River Basin

## A MULTISECTORAL DECISION SUPPORT SYSTEM APPROACH

Sustainable Development Department

South Asia Region

THE WORLD BANK

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# Abbreviations and Acronyms

| | |
|---|---|
| ADB | Asian Development Bank |
| AWARD | Afghanistan Water Resources Development |
| CIDA | Canadian International Development Agency |
| DSS | Decision Support System |
| FAO | Food and Agriculture Organization of the United Nations |
| GIS | Geographic Information System |
| GTZ | German Agency for Technical Cooperation |
| JICA | Japan International Cooperation Agency |
| MDG | Millennium Development Goal |
| USAID | U.S. Agency for International Development |

**Units**

1 $km^3$ = 1,000 $Mm^3$

1 Gl = 1,000 Ml = 1 $Mm^3$

1 $m^3/s$ = 31.54 $Mm^3$

1 l/s/day = 86.4 $m^3$/day = 8.6 mm/ha/day

**Currency Equivalent**

US$1.00 = Afg 49.9

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Given the multisectoral nature of the subject, the study has engaged, under the auspices of the Supreme Council for Water Affairs Management, the various government ministries and agencies active in the water sector: Ministry of Agriculture, Irrigation, and Livestock; Ministry of Urban Development; Ministry of Mines and Industry; Ministry of Rural Rehabilitation and Development; National Environmental Protection Agency; and the Kabul Municipality. In addition, valuable inputs were received from the various international development partners, notably the Asian Development Bank (ADB), the Canadian International Development Agency (CIDA), the European Union, the German Agency for Technical Cooperation (GTZ), the Japan International Cooperation Agency (JICA), KfW, the United Nations, the U.S. Army Corps of Engineers, and the U.S. Agency for International Development (USAID). The study would have been impossible without the participation of and knowledge contributions made by these government agencies and development organizations.

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# Executive Summary

***The overarching objective of this study is to develop an integrated basin planning framework for analyzing and prioritizing water resources development options in Afghanistan, and to demonstrate its application in the Kabul River basin.*** Accordingly, the study focuses on the tasks of (a) analyzing the medium- and long-term options for developing the water resources of the Kabul River basin for multiple purposes, including domestic and industrial water supply, hydropower, mining, irrigated agriculture, and environment; and (b) collating information on the basin, including the existing and potential water resources development options, water uses and demands, in a simple and user-friendly Decision Support System (DSS), so as to enable multisectoral analysis and optimization of development options in the basin by the concerned ministries and development partners. The study, conducted in collaboration with the government of Afghanistan, is expected to help strengthen the adoption of integrated approaches to basin planning and water resources management in the country.

***A long period of conflict has crippled Afghanistan's economy and exacerbated its poverty.*** The 2008 Afghanistan National Development Strategy reports that poverty was about 33 percent (head count) based on the 2005 summer and autumn surveys. A second survey undertaken in spring of 2007 estimated the poverty rate to be approximately 42 percent. A further 20 percent were situated slightly above the poverty line, indicating a high level of vulnerability. Food poverty was estimated to affect around 45 percent of Afghans.

***Afghanistan currently has a very low level of development of its water resources and correspondingly low levels of water-related services, including urban and rural water supplies, irrigation, hydropower, and other uses.*** In Kabul, a major city and one of the fastest growing in Asia, the current water production per capita is approximately 16 liters per person per day and is declining – one of the lowest for any city in the world (comparative figures: Delhi 240, Los Angeles 500). The per capita electricity consumption in Afghanistan is about 20–30 kilowatt-hours per year, which is again one of the lowest in the world (comparative figures: India 500, United States of America 13,000, global average 2,600). At present the electricity system has an installed capacity of only 350 megawatts, of which approximately 74 percent is hydroelectric power. In addition, about 133 megawatts of primarily diesel capacity has been installed since 2002, and the government is also importing electricity. Current production is less than the estimated demand from existing connected customers, and current unanswered demand is estimated to be more than twice the current energy availability. About 80 percent of Afghanistan's population is rural, and about 80 percent of the country's population is engaged primarily in agriculture. The farmers' traditional irrigation schemes have suffered from social disruption and breakdown of established systems of maintenance and repair. Overall, irrigated area in Afghanistan has fallen from a peak of over 3 million hectares to less than 1 million.

***Water resources development and management is central to Afghanistan's economic growth and poverty reduction efforts.*** Just as uncertain and inadequate water supply is constraining investment in high-value agriculture and agribusiness, inadequate and unreliable energy supply will constrain the government's efforts to promote industrial investment and employment growth. A low-cost, reliable, and long-term sustainable supply of energy is vital to achieving the government's development goals. How well the government is able to manage and develop these water resources will be a decisive factor in achieving food security, alleviating poverty, establishing reliable electricity supply to support broad-based growth, and securing safe and reliable domestic and industrial water supply.

***Since the new government came to power in 2002, a basin perspective and integrated water management have been the cornerstones of its approach to water resources development.*** A gradual transformation to integrated water resources management and a basin approach is in progress, with the consideration, by Parliament, of a new Water Law, which aims to provide an appropriate governance and policy framework for the future. To strengthen the transition to effective integrated water resources management, the government established the Supreme Council for Water Affairs Management to coordinate activities and overcome the problems of diverse ministerial responsibilities for water management, and to streamline decision making. A technical secretariat for the Supreme Council for Water Affairs Management was established under the leadership of the Ministry of Energy and Water, with representatives of all concerned ministries.

***However, there are some central issues that need to be addressed in order to make real progress:***

- There is a need to move in parallel to the ongoing long-term program of rehabilitation and small projects on a new track focused on the implementation of medium and larger projects in the water sector. As successful as rehabilitation programs have been, the investment in infrastructure has been insufficient for farmers and communities to (a) remove the constraint of low and highly variable streamflows in the growing season, (b) reduce the impact of frequent drought and unpredictable rains, and (c) provide a base for integrating with the growing and broader economy of the country.

- Projects need to be analyzed and prioritized in a multisectoral basin framework. The current problem is that most of the investments are conceived and prepared with sectoral "blinkers", for example as water supply, irrigation, or hydropower projects, and neither the intersectoral nor spatial location issues are adequately addressed. In addition, there is little in the way of any approach for prioritizing the numerous projects conceived in the universe of possible investments, and there is a tendency to prepare all of the possible projects through prefeasibility and feasibility studies. This not only stretches the already scarce financial and human resources of this postconflict country but also results in poorly prepared projects that are not linked to or coherent with other plans in the basin. It is absolutely critical that the projects are examined in a multisectoral basin context, as the viability and design of many projects are dependent on what happens to other projects. In addition, financial and human resources to effectively prepare, finance, and implement medium to large projects are very limited in Afghanistan.

- The capacity of the Ministry of Energy and Water for integrated water resources management and project preparation is weak. The Ministry lacks skilled human resources and experience in water management, especially in applying a basin approach to both water management and investment planning.

- Given Afghanistan's upstream location in several internationally shared river basins, water resources development in Afghanistan hinges critically on establishing cooperative agreements with the riparian countries. However, there is extremely limited capacity in Afghanistan to address the critical international dimensions of water resources development in the shared river basins. These capacity gaps need to be urgently addressed in order to ensure that Afghanistan can participate effectively and with a knowledge-based approach in the transboundary waters discussions with the other riparian countries.

***The study focuses on developing an integrated basin planning framework for analyzing and prioritizing water resources development options in the Kabul River basin.*** The Kabul River basin is arguably the most important river basin of Afghanistan. It accounts for 35 percent of the country's population, including half of the urban population. About 80 percent of the currently installed hydropower capacity in Afghanistan is in this basin. While it encompasses just 12 percent of the area of Afghanistan, the basin's mean annual streamflow is about 26 percent of the country's total streamflow volume. Kabul, the largest city and capital of Afghanistan, had an estimated population of 3 million in 2005, and is one of Asia's fastest growing cities. The Kabul River basin is strategically located for agriculture and agribusiness development, with historically prime areas of high-value horticulture. The basin also has very advantageous topography for the development of water storage and hydropower projects. Eight to ten favorable dam sites with substantial storage and hydroelectric capacity have been identified and studied in the basin at reconnaissance and prefeasibility levels.

***The specific planning objective of this study is to analyze the medium- and long-term options for development of the water resources in the Kabul River basin***. These include options for domestic and industrial water supply, hydropower, mining and ore processing, irrigated agriculture, and environment. An associated objective is to collect information on the basin, existing and potential water resources development options, and water uses and demands into a simple and readily used DSS. This would enable multisectoral analysis and optimization of development options in the basin by the concerned ministries with their development partners. Although shorter-term and smaller-scale projects are certainly going to be the focus for the next few years and even later, a conscious choice has been made in this study to focus on medium- to long-term options that need the benefit of basin planning analysis for identification and prioritization.

***At first glance, the Kabul River would appear to have more than ample water resources to meet future development needs in the basin. However, the distribution of water availability in time and space does not match well with demand.*** The Kabul River basin consists of three major watersheds:[1] (a) two watersheds that constitute the upper basin, namely the Logar-Upper Kabul and the Panjshir; and (b) a third, namely the Lower Kabul River watershed, into which the two upper basin watersheds discharge. The average outflow of the upper basin is about 19 percent of the flow of the Kabul River at Dakah where it crosses into Pakistan, this being the outflow of the entire Kabul River basin. Moreover, the Konar watershed, which joins the Kabul River just upstream of the point where it enters Pakistan, represents approximately 73 percent of the flow of the Kabul River at Dakah. A large portion of water demands on the river system are located in the upper basin, including the future water supply needs of Kabul and about 57 percent of the irrigable area in the basin. The Lower Kabul River basin, on the other hand, has large existing and planned hydroelectric power generation capacity, which, if developed, will place a demand on upstream water resources. This requires a shift of streamflow from the spring and summer months to the winter months, when there is peak electricity demand. Hence an important economic issue is the balancing of overall annual and monthly demand and supply of water in the basin, and its allocation in each subbasin over space and time.

***The study approach is to develop a DSS for the Kabul River basin.*** The DSS is used to analyze and assess various development options based on (a) cost, (b) water demands, (c) water availability, (d) economic impacts, (e) long-term consistency with development goals and trends in various sectors, and (f) sustainable use of the water resources base. The DSS has two elements:

- ***A knowledge base*** that encompasses all available data describing (a) water demands and uses, namely agriculture, domestic and industrial, mining, power generation, rural water supply, and the environment; (b) options for development and conveyance of water supply; and (c) the hydrological system.

- ***A mathematical model*** that enables one to determine the best possible combination of options to satisfy all demands by maximizing the total net economic benefit under a set of assumptions about (a) water demands, (b) constraints, and (c) future scenarios.

***All development options represent potentially viable projects.*** These include (a) 13 dam and reservoir projects, including eight with hydropower capacity of approximately 1,171 megawatts, three of which are run-of-river; (b) five groundwater aquifers; (c) 14 irrigation development areas; and (d) one major transbasin conveyance link connecting Kabul to the Panjshir watershed. Many of these options are being actively sponsored by sector departments to achieve their development objectives. Almost all these options have been proposed for investment since the 1970s, as seen in the proposed water sector portfolio of the Afghanistan National Development Strategy. They range in scope from

[1] A "watershed" is properly the dividing line between two river basins, but is often take to mean a river basin, subbasin, or catchment area.

small to very large in terms of capacity and service levels. All of these options attempt to develop and use a common hydrological resource – neither the options nor the water resources they are meant to utilize are independent. Many are alternatives for the same purpose whose requirements are changeable. Only a few of these options may be needed over the midterm period (2020–2030). Hence, taken together, they do not constitute a rational, sustainable, or efficient investment plan. Indeed, developed separately by individual sectors, they may result in serious water conflicts, foregone benefits, and increased costs.

***The DSS includes an optimization model that maximizes the net economic benefits of water used in various sectors.*** The model maximizes the net economic benefits of water development, which are defined as the gross benefit from irrigated agriculture and hydropower generation minus (a) the cost of storage, which includes the cost of the dam and electricity generation facilities; (b) irrigation investment; and (c) water conveyances, including pumping. The economic benefits of urban, rural, industrial and mining water use are not determined; instead these water demands are estimated and set as constraints to be satisfied as part of the optimal solution. For a given scenario or set of assumptions about the future, including water and electricity demands, the model is designed to determine an optimal set of strategic options. Implicitly, the model finds the sequence of monthly water allocations in the basin that results in the maximum net benefit and satisfies all specified constraints. This in turn allows the identification of a priority set of projects whose selection appears robust to repeated scenario and sensitivity analysis (to the many parameters where data are uncertain). These priority projects are ideally the ones where project preparation studies (for example prefeasibility and feasibility studies) should be undertaken. In this regard, it is important to note that the process does not identify the project (or projects) to definitely be implemented; however, it does help to narrow down the large universe of choices for further preparation, and allows such preparation to be more cognizant of the role of the project in the basin setting with respect to other projects. The DSS demonstrates how, even with significant data challenges, it is still possible to initiate meaningful multisectoral analyses to assist in decision making. The DSS can be updated over time as more information becomes available through ongoing and planned studies. Of course, it is also possible for a number of other simulation and optimization tools to be developed, or alternative formulations of welfare to be optimized to complement such analyses. In addition, several approaches, such as game theory, could also be used in future study. This particular study focused on developing and using methodologies that were compatible with data availability and client institutional capacity.

***The strategic findings of the study are summarized in Box ES.1, and in all cases the integrated multisectoral approach ensures that the results for a particular sector are consistent with the objectives and constraints presented by other sectors.***

***Strategy for accelerating water resources development in Afghanistan.*** In the larger context of national security and stability in Afghanistan, it is critical to increase the scale and accelerate the delivery of water resources projects. The analytical framework and tools developed by this study directly support the process of identifying priority investments in the Kabul River basin, and moving towards their implementation with coordinated international assistance. The strategy for accelerating new water resources development in Afghanistan needs to move in parallel along four tracks:

- ***In Kabul River basin: addressing key data gaps and preparing investment plan.*** As more and improved data are available, a revised basin analysis should be undertaken to strengthen this analytical framework, and use it as the basis for developing and implementing a Kabul River basin water resources development investment plan, with clear and prioritized investments. The different variations of the Kabul Medium-Term Plan outlined in this report could provide an appropriate starting-point.

- ***In other river basins: initiating multisectoral analysis and planning.*** While this study has been focused on the Kabul River basin, systematic and multisectoral analysis should be initiated at the earliest opportunity in other river basins of Afghanistan in order to

  - Address the lack of clarity on priority options that is resulting in delays and a poor use of resources dedicated to project preparation;
  - Understand the water resources situation at the national level, including possibly important interbasin linkages and dependencies, such as energy and food grain production;
  - Assess the combined set of identified priority options in the context of the financing envelope available for the water sector at the national level;

**BOX ES.1:** Key Findings for Water Resources Development in the Kabul River Basin

***Critical conveyance needs.*** A water conveyance link to bring water from the Panjshir subbasin is critical for supplying Kabul's population of more than 4 million. With this link, a Kabul population of up to 8 million can be served, and full supply of 43 million cubic meters per year can also be provided to the Aynak copper mine.

***Critical storage projects.*** The cheapest (lowest unit cost of bulk water supply) and most flexible option for meeting multisectoral demands in the Kabul River basin requires development of multipurpose storage in both the Panjshir and Logar-Upper Kabul subbasins. The critical storage projects are Panjshir (also called Gulbahar) in the Panjshir subbasin, and Kajab, Gat, and Haijan (Shatoot) in the Logar-Upper Kabul subbasin.

***Irrigation.*** The maximum irrigation development in the Kabul River basin is 184,000 hectares, under the assumption of a one-year drought whose probability of occurance is about 10% (once in 10 years).

***Tradeoff between irrigation and urban water supply.*** Irrigation water diversions in the Logar valley have significant implications for Kabul water supply. The irrigated area in the valley increases by 73 percent when no water is allocated to Kabul from the Logar River, but this increases the cost of Kabul bulk water supply by 25 percent.

***Hydropower production.*** With a mixed hydro-thermal electricity system, the Panjshir, Naglu, and Sarobi II cascade can meet the maximum projected energy demand in the Kabul River basin. A medium-term energy production plan would involve investments beginning with Panjshir and adding Sarobi II as demand rises. In case hydropower is the only source of energy production in the basin, the storage option at Konar is required to meet the maximum demand.

***Konar storage.*** The Konar storage project is a critical component of the Kabul River basin hydropower system, for meeting higher levels of demand (especially in the peak winter season) and for compensating for generation shortfalls elsewhere in the system.

***Baghdara versus Panjshir projects.*** While the currently available cost estimates suggest that the Baghdara project does not form a part of the optimal combination of options, updated cost estimates for the Panjshir project and resettlement and rehabilitation costs for all projects are needed to finalize the choice of Baghdara or Panjshir as the priority investment option in the Kabul River basin.

- Understand the levels of current and future use of water, which is fundamental to developing Afghanistan's position on the international water dimensions in each of the shared river basins.

The work supported by the international development partners on water resources infrastructure development in different basins of Afghanistan provides an excellent platform for moving this agenda forward.

- ***Capacity building for planning and investment preparation as a cross-cutting imperative.*** The Afghanistan National Development Strategy recognizes the need to focus strategically on addressing the capacity constraint at two main levels: integrated water resources management and improving the quality of project preparation. The government has initiated efforts for developing in-house multisectoral water planning capacity by establishing a Water Resources Planning Unit in the Ministry of Energy and Water. However, the government's current capacity is very limited, and efforts need to be started at the earliest opportunity on the following fronts:
  - Closing data gaps in the hydrological record;
  - Improving the quality of preparation studies to investment grade standards;
  - Updating project costs dating from the 1970s to the current environment;
  - Developing an appropriate set of planning tools for each basin;
  - Addressing the constraint of limited staff and skills base.
  - In addition, there is a critical need for constituting a multidisciplinary Afghan transboundary waters team, so that the various efforts of capacity building on this vital subject can be focused and coordinated.

- ***Strengthening institutions for multisectoral water resources decision making.*** As mentioned earlier, a start has been made on intersectoral coordination with the establishment of a Supreme Council for Water Affairs Management, which incorporates the key water-related ministries and agencies of the government. The Supreme Council is headed by the First Vice-President of Afghanistan, and judged by its design, it is the most progressive institution for intersectoral water resources decision making in Central and South Asia. However, achieving real coordination between different ministries at the decision-making level will be very challenging in practice, and leadership will be required from both the Supreme Council for Water Affairs Management and the Ministry of Energy and Water for

- Effectively managing the finalization of the basin development plan for the Kabul River basin, and initiating preparation of similar plans for other river basins in Afghanistan, working closely with different sector ministries and other stakeholders;
- Coordinating decision making within the government on multipurpose water infrastructure investments, building consensus on and ensuring acceptance of investment plans by different sectoral interests.

***Progress on first steps.*** In 2008, the World Bank was requested by the government to provide technical assistance for building Afghanistan's capacity for strategic basin planning and project preparation. Given the significance of the agenda and the need to coordinate water sector assistance from international development partners, it was proposed that technical assistance be supported by the multidonor Afghanistan Reconstruction Trust Fund. The Afghanistan Water Resources Development (AWARD) technical assistance project was approved in December 2008 and became effective in early 2009. The project aims at capacity building of government agencies for water resources development planning in an integrated basin context and for effective project preparation. The technical assistance is provided in a learning-by-doing mode, and is intended to deepen and broaden the analytical framework developed in this study, with the target of building in-house water resources institutional capacity in the government of Afghanistan. Accordingly, the Ministry of Energy and Water staff and external expert consultants would work together on the execution of tasks and studies under the scope of the project, with the role of the consultants gradually scaled down as Ministry of Energy and Water staff increasingly take on technical responsibilities. The scope of work for the AWARD technical assistance project includes basin planning for selected major basins, whereby strategic basin planning would be conducted in close collaboration with the international development partners active in each basin, for example the European Commission in Kunduz basin, the U.S. Agency for International Development (USAID) and the Canadian International Development Agency (CIDA) in Helmand basin, and the Asian Development Bank (ADB) in Balkh and the western basins, to identify priority investments. Project preparation resources would be focused on identified priority investments, supported in the preparation and implementation phases by development partners based on their geographic and sectoral emphases. This umbrella institutional framework, being developed and implemented by the government, is being endorsed by the development partners in the water sector, so that international support can be coordinated and synergized to accelerate the much-needed water resources development in Afghanistan.

# 1

# Introduction

## Background

The centrality of water resources to Afghanistan's economic, social, and cultural life cannot be overstated. How well the government is able to manage and develop these water resources will be a decisive factor in achieving the well being and prosperity of the Afghan people in terms of (a) achieving food security, (b) alleviating poverty, (c) establishing a reliable electricity supply to support broad-based growth, and (d) securing safe and reliable domestic and industrial water supply.

The average water resources availability in Afghanistan is 2,280 cubic meters per year per capita, but this comfortable average value masks strong temporal and spatial variations in the distribution of water. Precipitation is primarily in the form of snowfall and is very uneven across the country. Due to insufficient storage capacity in the river basins, a substantial fraction of the snowmelt that runs off in the beginning summer months is not harnessed for productive use. The melting of snowpack will be accelerated by the increasing summer temperatures expected due to climate change, and will put further stress on groundwater resources for meeting the growing water needs in each sector.

Since the new government came to power in 2002, a basin approach and integrated water resources management have been the cornerstones of its action plan for water resources development. Although a gradual transformation to integrated water resources management is in progress, the vast majority of current development activities are still being planned and implemented on a project-by-project basis. The integrated water resources management process rests on three fundamental pillars: (a) a governance framework for the river basin that includes a sound and equitable policy structure and institutional arrangements to ensure sustainable water management with efficient water use, (b) a framework for effective participation of all basin stakeholders in planning and decision making, and (c) an analytical framework and knowledge base with which planning and decision making can be informed and made fully participatory and effective.

The proposed new Water Law, approved by the Cabinet and now before Parliament will establish the statutory and policy framework to implement integrated water resources management including the transition from a centralized to a decentralized institutional structure. Decentralization will establish jurisdictional boundaries conforming to natural river basins, further divided into subbasins. The transition to a river basin organization for improved water resources management and institutional setup is being experimented with in the northern frontier region of the Amu Darya River basin. Experience gained from this and other pilots will facilitate the implementation of further river basin organization projects throughout the country. All stakeholders are expected to participate in water sector development and management in their river basins or subbasins.

The erstwhile Ministry of Water and Power carried out and managed extensive river basin and project identification studies during the 1970s and early 1980s. Though it implemented a number of important projects at that time, not much has been done since then; most of the technically skilled and experienced staff left the Ministry and the country during the intervening years. Several earlier studies and accompanying data are irretrievable. At present, the Ministry has limited capacity to organize, implement, and manage a program to plan and develop water conservation infrastructure and implement river basin management of water resources. It is important to create new capacity for this purpose. Experience from successful government-implemented projects, such as the Emergency Irrigation Rehabilitation Project, shows that this capacity can be created with patience, well-designed technical assistance, and specific work programs that can serve as a context for capacity building.

## Objectives of This Study

The overarching objective of this study is to develop an integrated basin planning framework for analyzing and prioritizing water resources development options, and to demonstrate its application in the Kabul River basin in Afghanistan. Accordingly, the study focused on the tasks of (a) analyzing the medium- and long-term options for developing the water resources of the Kabul River basin for multiple purposes, including domestic and industrial water supply, hydropower, mining, irrigated agriculture, and environment; and (b) collating information on the Kabul River basin, including the existing and potential water resources development options, water uses, and demands, in a simple and user-friendly Decision Support System (DSS), so as to enable multisectoral analysis and optimization of development options in the basin by the concerned ministries and development partners.

An associated objective of this study is to demonstrate the value of the multisectoral and basin-level water resources planning approach, as opposed to the project-by-project and sector-by-sector "silo" approaches that have defined water resources planning in Afghanistan so far.

This study report is primarily aimed at two audiences. The first comprises senior decision makers in the government of Afghanistan, and in the international development agencies active in the water sector in Afghanistan, charged with planning and implementation of water resources development in the country. The second comprises the technical and water resources planning specialists in the various government ministries and development agencies. This report brings together the available information and descriptions of the analytical approach and strategic findings in one volume. In addition to this report, a summary version with an emphasis on key findings, actions needed, and policy implications will be prepared during the dissemination phase, specifically aimed at senior water sector decision makers in Afghanistan.

## Approach and Process

The approach of this study is to develop a DSS for the Kabul River basin in Afghanistan and to use it to analyze and assess development options based on their cost, water demands, water availability, economic impacts, and long-term consistency with development goals and trends in various sectors, while ensuring sustainable use of the water resources base. The DSS consists of two major components: an economic optimization model and a knowledge base.

This study was carried out with close client collaboration. The primary activities included a review of existing reports (as outlined in the next section) and detailed interaction with a range of different agencies and individuals in Afghanistan, who collaborated with inputs and feedback on a number of different aspects of this study. They included the officials and consultants at various levels of several water-related ministries (including the Ministry of Energy and Water, Ministry of Agriculture, Irrigation, and Livestock, Ministry of Mines and Industry, Ministry of Urban Development, Ministry of Environment, and Ministry of Finance), the Afghanistan National Development Strategy secretariat, the Supreme Council for Water Affairs Management, academia, World Bank colleagues, and other development partners.

Numerous presentations were made by the study team to these counterparts, including several joint high-level multisectoral meetings. The discussions with the various counterparts helped define the scope of the study in terms of the geographic extent (expanded from an original focus on the Upper Kabul River basin) and issues covered, and provided guidance on sources of information and other relevant work on the basin. The young counterpart team, set up to sustain this work at the initiative of the Minister of

Energy and Water, formed the core of the Water Resources Planning Unit at the Ministry of Energy and Water and was also instrumental in collating additional data for this study. The work on this study has helped improve discussions on intersectoral issues relating to projects in the Kabul River basin, and has also helped shape the Afghanistan Water Resources Development (AWARD) technical assistance project financed by the Afghanistan Reconstruction Trust Fund, which has recently been initiated to strengthen multisectoral basin planning and quality project preparation functions at the Ministry of Energy and Water.

The Kabul River basin is an international basin shared between Afghanistan and Pakistan. The scope of this study is limited to analysis and prioritization of water resources investment options within the Kabul River basin in Afghanistan, and does not include an analysis of the transboundary waters dimensions in the basin.

## Sources of Information

One important consequence of the long period of civil conflict and war, beginning in the early 1980s and extending through 2002, is the steady decline in data and monitoring networks, and in research and planning.[2] Nearly every aspect of the knowledge base on which water resources management and development depends has deteriorated or been lost. New thinking and analysis of current problems must therefore depend on old planning studies from the 1960s to the early 1980s, and the few recent studies carried out since the new government was formed in 2002.

Of the recent studies, the most important are the feasibility study for a Kabul water supply system (Beller Consult 2004) and the prefeasibility study of the Baghdara hydroelectric project (Fichtner Consulting Engineers 2007). Other studies include (a) the Power Sector Master Plan, completed in 2004 (Norconsult and Norplan 2004) for the Ministry of Energy and Water; (b) Interim Report for Rapid Assessment and Inception Framework for Water Resources Management completed in 2003 by Sheladia Associates for the Ministry of Irrigation, Water Resources, and Environment; and (c) the *Watershed Atlas of Afghanistan*, prepared by the Afghanistan Information Management Service with assistance from the Food and Agriculture Organization of the United Nations (FAO) (Favre and Kamal 2004).

During the 1970s, the government carried out a number of river basin planning and project preparation studies aimed at identifying potential developments for irrigation, domestic and industrial water supply, and hydropower; establishing priorities; and initiating detailed studies and investments. For the Kabul River basin, the Montreal Engineering Company (1978) completed a reconnaissance-level river basin development plan, referred to as the Kabul River Basin Master Plan (1979). This study was in two volumes, which (a) collated the knowledge base for the basin up to 1979; (b) included the identification and preliminary evaluation of storage sites; (c) estimated domestic, industrial, and agricultural water demands; (d) assessed the availability of water resources; (e) prepared preliminary cost estimates for infrastructure suitable for comparative purposes; (f) carried out an integrated analysis of development potential, including power generation, irrigation, and drinking water supply, based partly on a computer simulation model; and (g) established investment priorities for project preparation and development.

As part of the program of cooperation between the government and the Islamic Republic of Iran, the consulting firm Toosab (Tehran) and the Regional Center for Urban Water Management (Tehran) carried out a basin planning and simulation modeling study of the Kabul River basin in 2006 (Toosab and RCUWM 2006). This included a detailed water resources assessment, and developed and used a hydrological simulation of the basin to study water supply and demand based on full development of the basin. However, the study did not include an optimization analysis or a prioritization of water resources investment options in the basin.

With few exceptions, the data and information on which new planning studies depend must be drawn from these and other earlier studies. The Kabul water supply feasibility studies, for example, reviewed available hydrogeological data and studies carried out in the Upper Kabul River basin from the 1960s to the present, but were unable to undertake new exploration and investigation

[2] The FAO Afghanistan Agricultural Strategy report (FAO-TCP 1997) noted that the entire hydrological monitoring network was either destroyed or dysfunctional.

apart from a limited number of pump tests of selected existing wells. However, that study added new surveys of water consumers in Kabul, updated and derived new population estimates, evaluated existing water sources, and investigated the distribution system and related infrastructure. Most of the studies so far have focused on either a narrow, sectoral approach, or a project-by-project approach that does not do justice to the interrelationships among these projects in a spatial basin or cross-sectoral context.

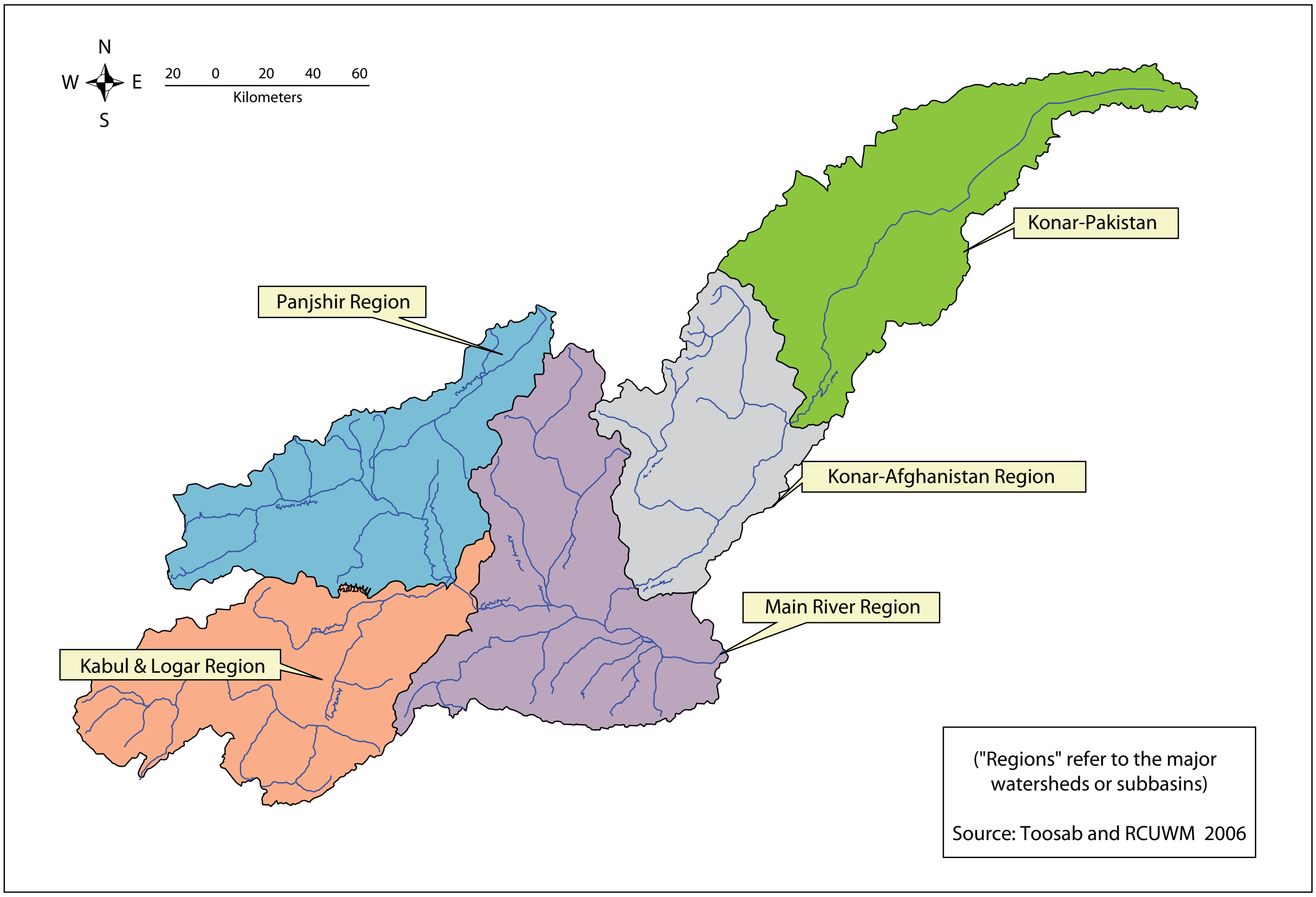
2

# The Kabul River Basin

Almost 90 percent of Afghanistan's land area is located in the five river basins, namely the Amu Darya, the Helmand, the Harirud-Murghab, the Kabul, and the western river basins. There is significant engagement of various international development partners in the water resources development agenda in Afghanistan, with efforts focused

**Figure 2.1:** Location of Kabul River Basin

**Figure 2.2:** Kabul River Subbasins




at the central level as well as in their respective selected river basins. A summary of these engagements in provided in appendix A.

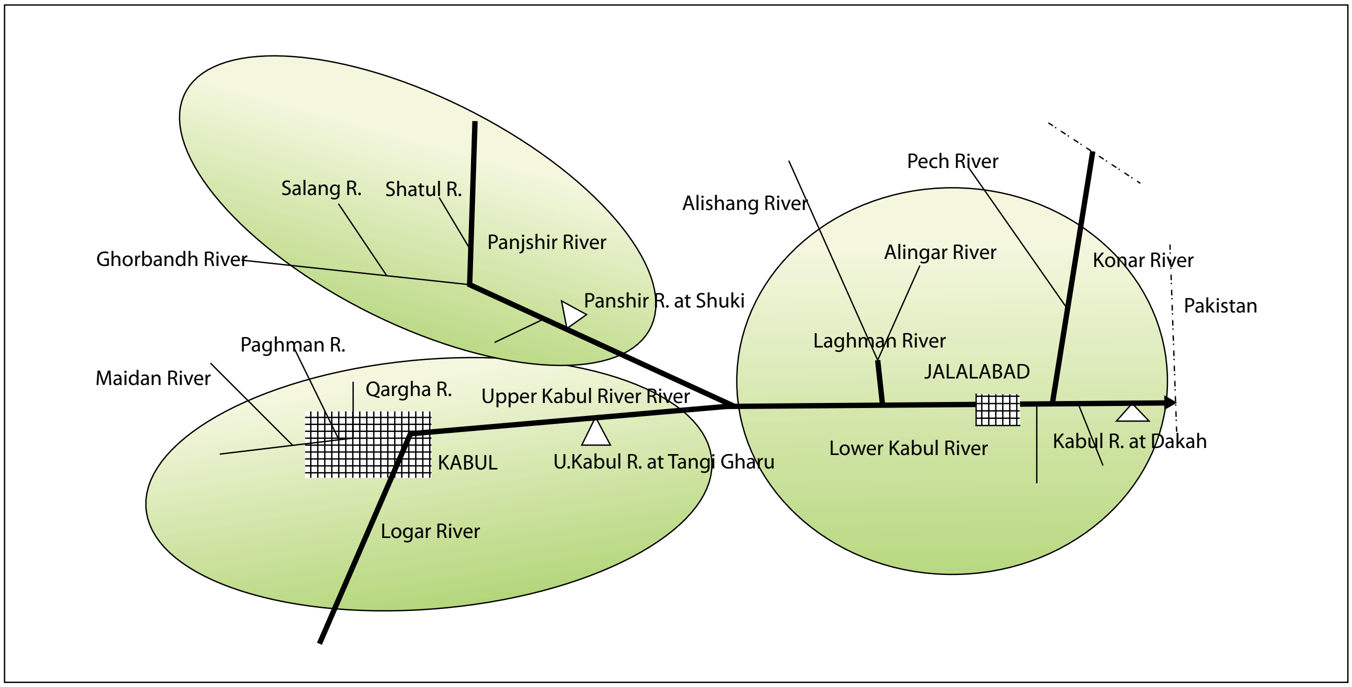
The Kabul River basin lies in the northeast quarter of Afghanistan. The river flows west to east, joining the Indus River in Pakistan's Northwest Frontier Province (figure 2.1). Even though it encompasses just 12 percent of the area of Afghanistan (Favre and Kamal 2004, Part III), it accounts for 35 percent of the population, and has the fastest population growth rate in the country. The basin includes the Kabul urban area, which is one of the biggest engines of economic growth in the country, and has a large fraction of the installed energy generation capacity.

The northern or left flank of the basin is extremely mountainous, while the southern portions drain mainly low mountain ranges, foothills, and plains. The left bank tributaries (figure 2.2), which drain these northern, mountainous watersheds with elevations ranging from 400 to over 6,000 meters above sea level, provide most of the flow of the Kabul River. The climate of the basin is characterized by cold winters with maximum precipitation from November to May, and warm to very hot summers with little or no precipitation or streamflow, except in rivers and streams fed by melting snow and glaciers. Rainfall is highly variable throughout the basin.

The eastern portion of the basin includes extensive but rapidly diminishing forests that comprise nearly 93 percent of the country's forest area. Rangeland is limited to approximately 13 percent of the national total, as is rain-fed agriculture, which accounts for only 3.5 percent of the country's total rain-fed agricultural area.

Irrigated land in the basin, with intensive cultivation of one or two crops per year, is currently estimated to be 306,000 hectares, or nearly 20 percent of the estimated

**Figure 2.3:** Schematic Diagram of the Kabul River Sub-basins




1.56 million hectares of irrigated area in Afghanistan.[3] The four existing hydroelectric power stations in the Kabul River basin form the core of the country's electric power system.

## The Principal Subbasins

From the standpoint of climate, hydrology, and physiographic characteristics, the Kabul River basin is divided into three distinct subbasins. The upper basin consists of two major subbasins – the Panjshir subbasin and the Logar-Upper Kabul subbasin. The third subbasin is the Lower Kabul, which encompasses the watershed area from the confluence of the Panjshir and Upper Kabul rivers near the head of the Naglu reservoir to the border with Pakistan. This subdivision of the basin[4] is shown in figure 2.2 and is depicted in schematic form in figure 2.3.

[3] This figure is roughly half of the approximately 3 million hectares estimated by FAO to be irrigated in the early 1990s.

[4] The recent study by Toosab Consulting Engineers and the Regional Center for Urban Water Management (Toosab and RCUWM 2006) contains a more detailed analysis of the watersheds within these subbasins. The Toosab and RCUWM study is based in part on the application of a hydrological simulation model of the basin, which was not available to the team that undertook this study.

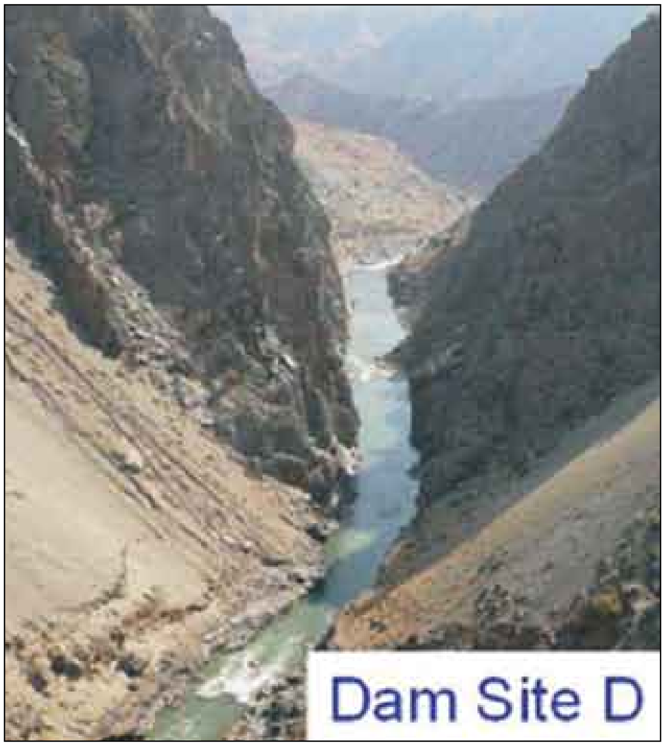
### The Logar-Upper Kabul Subbasin

This subbasin comprises two watersheds: (a) the Upper Kabul River, which, with three small rivers, the Maidan, Paghman, and Qargha, originates upstream of Kabul and flows through the center of the city; and (b) the Logar River, which drains a dry and hilly watershed south of the city. The Logar watershed comprises approximately 75 percent of the drainage area of the Logar-Kabul subbasin above the gauging site at Tangi Gharu (figure 2.3). There is modest but significant irrigated agriculture along the Logar River valley and in the river valleys upstream of Kabul. There are also several small hydroelectric stations on minor tributaries. However, the dominant feature of this subbasin is Kabul, which is the largest city in Afghanistan, and the economic and administrative center of the country.

### The Panjshir Subbasin

To the north of the Logar-Upper Kabul subbasin is the Panjshir subbasin, formed by the Panjshir River and its principal and much smaller tributaries, the Ghorband, Salang, and Shatul rivers (figure 2.3). The upper portion of this watershed consists of steep mountain valleys in the Hindu

**Figure 2.4:** Proposed Baghdara Dam Site on the Panjshir River




Kush mountain range, which reaches over 6,000 meters above sea level and remains snow covered throughout the year. The southern portion of the watershed, namely the right bank areas of the Ghorband and Panjshir rivers near their confluence, opens onto the broad and gently sloping fertile Shomali Plain which has some of the most important irrigated land in the basin. Downstream of the confluence with the Ghorband River and below the gauging station at Shukhi, the Panjshir River flows through a steep, narrow gorge (figure 2.4, which shows the gorge along with the proposed dam site at Baghdara) until it joins the Upper Kabul River. Although the drainage area of the Panjshir River at Shukhi (figure 2.3) is smaller at approximately 84 percent compared with the Upper Kabul River at Tangi Gharu, its average annual streamflow is over 6 times as large.

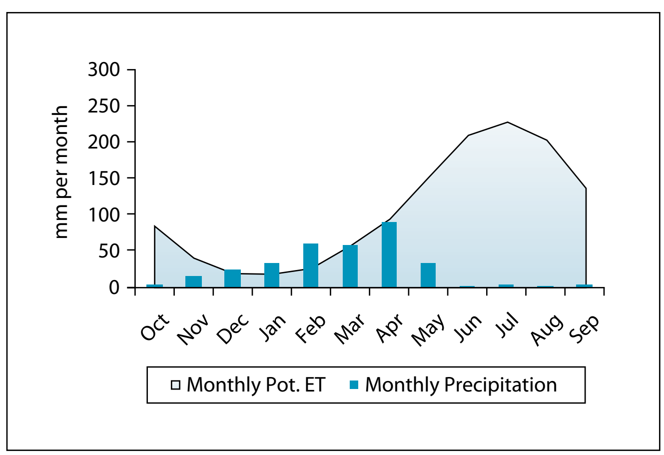
## The Lower Kabul Subbasin

The Lower Kabul subbasin extends from the confluence of the Panjshir and Upper Kabul rivers to the Pakistan border. It comprises two large watersheds to the north or left bank of the main stem of the river. These are (a) the Laghman, which includes the Alishang and Alimghar rivers; and (b) the Konar, which includes the Pech River and originates in Pakistan. There are numerous small tributaries on the right bank, including the Surkhrud near Jalalabad, which, with a population of approximately 120,000, is the only large city in the Lower Kabul subbasin. The main stem of the Kabul River runs eastward from the confluence with the Upper Kabul and Panjshir rivers through a narrow gorge until its confluence with the Laghman River, where the valley begins to widen. As the main stem of the river continues eastward, the valley widens into a broad plain that comprises the second largest and important agricultural area in the Kabul River basin. Three dams and reservoirs have been constructed in this gorge for hydropower. The lowest reservoir in this cascade, at Darunta, is just upstream of Jalalabad, and also provides municipal and irrigation water supply. Streamflow in the lower basin comes predominately from the two large, mountainous watersheds, namely the Laghman and the Konar, whose higher snow- and glacier-covered areas reach nearly 6,500 meters above sea level. Except for the high mountain areas to the north, the climate of this lower region is influenced by the southwest monsoon, with a few days each year of hard frost or freezing temperatures.

## Climate and Hydrology

A comparison of average monthly precipitation and potential evapotranspiration at the meteorological stations at Kabul and Jabul-Saraj on the Ghorband River, upstream of the confluence with the Panjshir, is shown in figures 2.5 and 2.6. The record at Kabul is typical of

**Figure 2.5:** Average Monthly Precipitation and Potential Evapotranspiration at Kabul



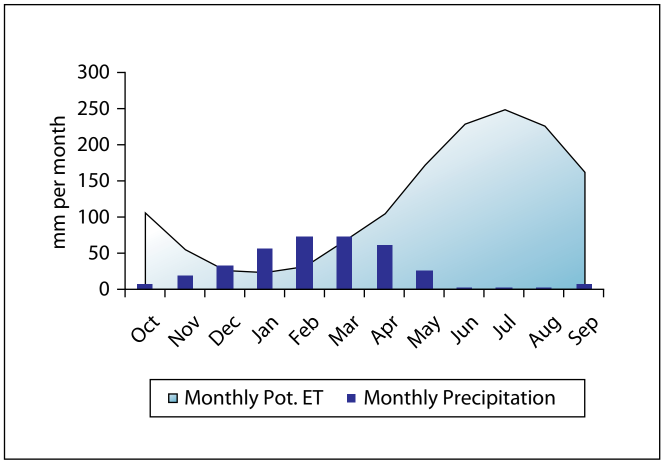



**Figure 2.6:** Average Monthly Precipitation and Potential Evapotranspiration at Jabul-Saraj

the Logar-Upper Kabul subbasin. However, the pattern of precipitation and evapotranspiration at Jabul-Saraj is not typical of the Panjshir subbasin except for the broad plain extending south from the Ghorband and Panjshir rivers (figure 2.3). Northward of this area precipitation increases sharply, mainly as snow at higher altitudes. For example, the average precipitation at South Salang in the upper portion of the Salang River watershed (figure 2.3) is over 1,000 millimeters, or 2.5 times the precipitation at Kabul or Jabul-Saraj. The potential evapotranspiration here is equal to or greater than the precipitation at both stations except in the rainiest month. While the overall annual pattern of rainfall and potential evapotranspiration is similar in the Lower Kabul subbasin as measured at the Jalalabad station (figure 2.7), it is to be noted that potential evapotranspiration exceeds the rainfall in all months. This region is much drier and warmer than the upper two subbasins (Toosab and RCUWM 2006, Volume 8 Agriculture, chapters 2 and 8).

Despite the similarities evident in figures 2.5 and 2.6 the great difference in the hydrology of the Logar-Upper Kabul and Panjshir subbasins is shown in figure 2.8, in terms of average monthly streamflow volume at the two downstream gauging stations, Tangi Gharu and Shukhi (see figure 2.3). These differing characteristics are summarized in table 2.1. The Logar-Upper Kabul subbasin derives its flow from precipitation in the winter and spring, but the Panjshir subbasin streamflow originates predominately from snow and glacial melt, with the peak flow occurring after the warm summer temperatures begin. The baseflow of the Logar-Upper Kabul subbasin in the dry summer months is very small, when irrigation water demand is highest, but is substantial in the Panjshir watershed.

The average monthly streamflow in the three subbasins is shown in figure 2.9. The outflow from the Logar-Upper Kabul subbasin peaks earliest, that is during January to March, but is only about 15–20 percent of the outflow of the basin during those peak months. The outflow of the Panjshir subbasin does not peak until June, when it is about 33 percent of the outflow of the basin at Dakah. The peak outflow of the Lower Kabul River occurs still later in July because the peak outflow of the Konar River is in July and the latter represents about 77 percent of the outflow of the basin in that month. In August, September, and October, the outflow of the Konar River is over 80 percent of the outflow of the basin (figure 2.10).

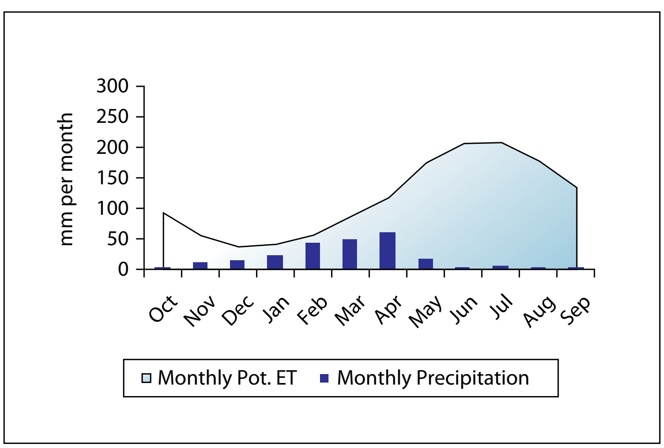



**Figure 2.7:** Average Monthly Precipitation and Potential Evapotranspiration at Jalalabad

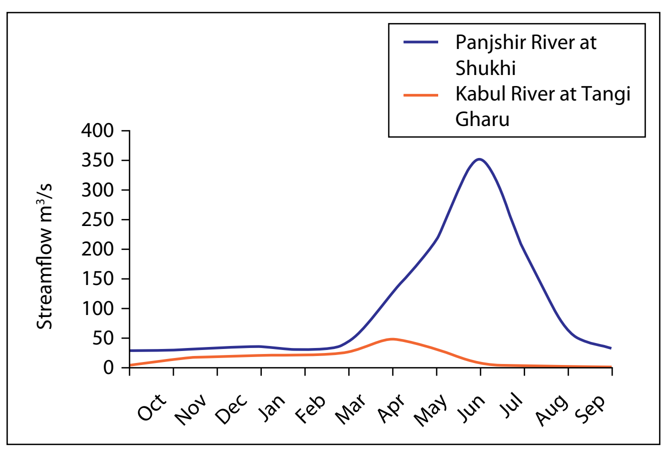



**Figure 2.8:** Panjshir and Logar-Upper Kabul Subbasins Comparison of Average Monthly Streamflow ($m^3/s$)

**Figure 2.9:** Kabul River Subbasins Average Monthly Streamflow

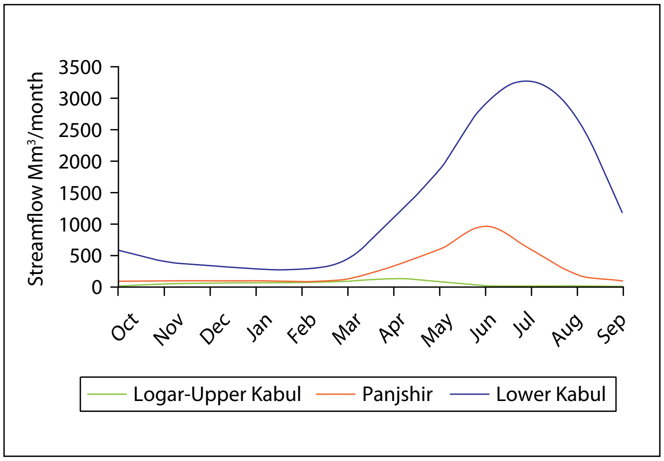



**Figure 2.10:** Konar and Kabul Rivers Average Monthly Streamflow

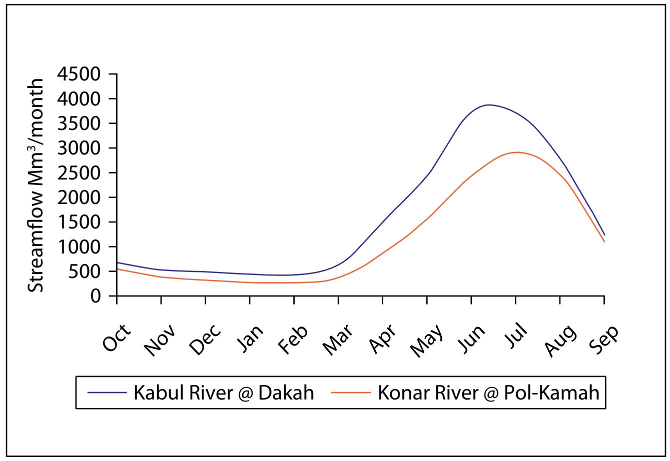



**Table 2.1 Comparison of Kabul River Subbasins**

| Subbasin | Drainage area (km²) | Avg. flow (m³/s) | Avg. annual flow (Mm³/yr) | Yield (l/sec/km²) | Yield (Mm³/yr/km²) |
|---|---|---|---|---|---|
| **Logar-Upper Kabul at Tangi Gharu** | 12,850 | 15.68 | 495 | 1.22 | 0.038 |
| **Panjshir at Shukhi** | 10,850 | 103.29 | 3,258 | 9.52 | 0.300 |
| **Lower Kabul at Dakah** | 43,660 | 611.60 | 19,287 | 11.28 | 0.442 |

*Sources: Montreal Engineering Company 1978, Vol. II, appendix A & AA; Toosab and RCUWM 2006.*

**Table 2.2 Average Monthly Rainfall at Selected Sites in the Kabul River Basin**

| Watershed | Climate station site | Average monthly rainfall (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | J | J | A | S | O | N | D | J | F | M | A | M | Total |
| Logar-Upper Kabul | Logar (airport site) | 2 | 3 | 2 | 1 | 3 | 13 | 17 | 28 | 42 | 43 | 49 | 17 | 220 |
| | Kabul | 1 | 4 | 1 | 3 | 3 | 16 | 23 | 33 | 60 | 59 | 90 | 32 | 325 |
| Panjshir | Jabul-Saraj | 2 | 2 | 2 | 5 | 7 | 17 | 31 | 56 | 72 | 73 | 60 | 25 | 352 |
| Lower Kabul | Jalalabad | 2.7 | 10.6 | 14.8 | 24.4 | 43.7 | 48.5 | 61.2 | 17.6 | 1.0 | 5.4 | 1.2 | 2.7 | 233.8 |

*Sources: Montreal Engineering Company 1978, Vol. II, annex E; for Lower Kabul, Toosab and RCUWM 2006.*

The average climate data used for reservoir and irrigation sites in the two watersheds are summarized in tables 2.2 and 2.3. Average monthly streamflow at the principal river sites is shown in figure 2.9.

## Demographics and Land Use

The Kabul River basin includes 23 percent of the settlements in Afghanistan and approximately 35 percent of the country's population. The population density in the basin averages 93 persons per square kilometer, or approximately 3 times that in the country's four other international river basins, principally because of the heavy density in and around Kabul.

The Kabul River basin encompasses some or all portions of nine provinces (table 2.4).[5] The basin includes 101 districts, 34 cities, and an estimated 5,567 villages. Table 2.5 summarizes the estimated urban and rural population

[5] The study did not have access to extensive geographic information system (GIS) data and recent surveys that would have enabled a more detailed analysis of the distribution of population within the Kabul River basin watersheds and its smaller subbasins. Toosab and RCUWM (2006) did develop a GIS of the basin in conjunction with the development of the hydrological simulation model. These and other GIS data are expected to be used extensively in future work with the DSS developed in this study and with the Toosab and RCUWM model.

| Table 2.3 Average Monthly Evapotranspiration at Selected Sites in the Kabul River Basin | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Watershed** | **Climate station site** | **Average monthly evapotranspiration (mm/day)** | | | | | | | | | | | | |
| | | **J** | **J** | **A** | **S** | **O** | **N** | **D** | **J** | **F** | **M** | **A** | **M** | **Total** |
| Logar-Upper Kabul | Logar (airport site) | 6.66 | 7.34 | 6.54 | 4.55 | 2.63 | 1.23 | 0.46 | 0.32 | 0.64 | 1.63 | 3.11 | 4.78 | 1,215.48 |
| | Kabul | 7.02 | 7.38 | 6.58 | 4.58 | 2.74 | 1.36 | 0.63 | 0.60 | 0.95 | 1.87 | 3.16 | 4.94 | 1,273.99 |
| Panjshir | Jabul-Saraj | 7.71 | 8.11 | 7.37 | 5.46 | 3.45 | 1.85 | 0.85 | 0.76 | 1.14 | 2.20 | 3.53 | 5.61 | 1,463.18 |
| Lower Kabul | Jalalabad | 2.98 | 1.84 | 1.19 | 1.32 | 2.00 | 2.80 | 3.91 | 5.63 | 6.87 | 6.69 | 5.72 | 4.46 | 1,384.63 |

*Sources: Montreal Engineering Company 1978, Vol. II, annex E; for Lower Kabul, Toosab and RCUWM 2006.*

| Table 2.4 Provinces Constituting the Kabul River Basin: Total Population by Province, Including Refugees | | | | | | |
|---|---|---|---|---|---|---|
| **Province** | **Males** | **Females** | **Total** | **Refugees UNHCR** | **Total population** | **% of total** |
| | **(thousands)** | | | | | |
| **Kabul** | 1,729.1 | 1,584.7 | 3,313.8 | 656.4 | 3,970.2 | 48.5 |
| **Logar** | 149.5 | 142.0 | 291.5 | 26.6 | 318.1 | 3.9 |
| **Wardak** | 211.8 | 201.2 | 413.0 | 12.3 | 425.3 | 5.2 |
| **Parwan** | 372.8 | 353.6 | 726.4 | 101.4 | 827.8 | 10.1 |
| **Kapisa** | 184.5 | 175.2 | 359.7 | 23.0 | 382.7 | 4.7 |
| **Nangarhar** | 559.6 | 529.5 | 1,089.1 | 313.9 | 1,403.0 | 17.1 |
| **Konar** | 164.7 | 156.5 | 321.2 | 11.0 | 332.2 | 4.0 |
| **Laghman** | 191.1 | 181.5 | 372.6 | 38.8 | 411.4 | 5.0 |
| **Nuristan** | 57.3 | 54.4 | 111.7 | 0.10 | 111.8 | 1.4 |
| **Total** | 3,621.25 | 3,378.6 | 6,999.0 | 1,183.5 | 8,182.5 | |

*Source: Central Statistical Office 2002, after Scheladia 2004, Vol. II, annexes, table 1.*

in these provinces and the growth rate between 1979 and 2003.

With the exception of the urban and peri-urban area of Kabul and the city of Jalalabad in the Lower Kabul subbasin (Nangarhar Province), the Kabul River basin is predominately rural and sparsely populated. Population growth rates are quite modest except in Kabul. The population is concentrated along river courses and in the adjacent valleys where space and water are accessible for irrigating the summer crop. Consequently, the construction of new storage reservoirs is likely to involve extensive resettlement and compensation of people displaced by the reservoirs.[6]

[6] An exception to this are the hydroelectric projects at Baghdara (on the Panjshir River) and Sarobi II (on the main stem of the Kabul River in the Lower Kabul subbasin). Both are located in deep, narrow gorges without settlements. However, the prefeasibility study of Baghdara found it necessary to move the preferred dam site downstream and lower its height to avoid extending the reservoir upstream of the gorge to densely populated and extensively cultivated areas. This is likely to be a major problem for the important storage projects proposed on the Logar River near Kabul.

Agriculture in the Kabul River basin is generally limited to land along the river valleys with access to the river for irrigation. The exceptions are the broad plain stretching southward from the Ghorband and Panjshir rivers, the lower Logar valley, areas adjacent to Kabul, and the wide valley of the Kabul River east of Jalalabad. These areas represent the greatest potential in the Kabul River basin for intensive cultivation of high-value crops. These large contiguous agricultural areas are also close to the primary transport routes and the largest economic centers.

If water supply is reliable throughout the summer season, irrigated agriculture is intensive. Intermittent irrigation is practiced where access is more uncertain, both within the season and from year to year. There is also a relatively small area of rain-fed agriculture. The existing and potential irrigated areas within the Upper Kabul River basin total approximately 352,000 hectares (table 2.6). The area shown as potentially irrigable

| Table 2.5 Urban and Rural Population in the Kabul River Basin | | | | |
|---|---|---|---|---|
| **Province** | **Urban** | **Rural** | **Total** | **Est. growth rate (%) (1979–2003)** |
| **Kabul** | 2,839,100 | 615,900 | 3,445,000 | 3.91 |
| **Logar** | 7,800 | 307,600 | 315,400 | 1.58 |
| **Wardak** | 3,200 | 445,500 | 448,700 | 1.87 |
| **Parwan** | 37,200 | 700,000 | 737,200 | 1.59 |
| **Kapisa** | 1,900 | 363,000 | 364,900 | 1.58 |
| **Nangarhar** | 101,700 | 1,004,000 | 1,105,700 | 1.56 |
| **Konar** | 3,300 | 324,800 | 328,100 | 1.14 |
| **Laghman** | 6,200 | 371,900 | 378,100 | 0.82 |
| **Nuristan** | 0 | 111,600 | 111,600 | 0 |
| **Total** | 3,000,400 | 4,244,300 | 7,244,700 | |

*Source: Central Statistical Office 2003, after Toosab and RCUWM 2006, Vol. 6, Population.*

| Table 2.6 Existing and Potential Irrigated Agriculture in the Kabul River Basin | | | |
|---|---|---|---|
| **Subbasin** | **Irrigated area (ha)** | | |
| | **Intensive** | **Intermittent** | **Potential** |
| **Logar-Upper Kabul subbasin** | | | |
| Logar River watershed | | | |
| Logar River valley above proposed Gat dam site | 17,875 | 21,875 | |
| Logar River valley below proposed Gat dam site | 2,700 | 7,300 | |
| Upper Kabul River watershed | | | |
| Upper Kabul, Maidan, and Paghman | 11,730 | 17,010 | |
| East of Kabul City | | | 37,330 |
| **Panjshir subbasin** | | | |
| Panjshir River (Kapisa) | 17,040 | 1,000 | 4,000 |
| Panjshir, Ghorband, Salang, Shatul | 38,210 | 600 | 18,000 |
| Barikaw | 11,320 | 6,500 | |
| **Lower Kabul subbasin** | | | |
| Laghman | 18,935 | 2,043 | |
| Konar | 12,010 | 10,420 | |
| Nangarhar | 66,786 | 29,326 | |
| ***Total*** | **1,96,606** | **96,074** | **59,330** |

*Sources: Montreal Engineering Company 1978; FAO 1965; for Lower Kabul, FAO 1993, after Scheladia 2004, Vol. II.*

| Table 2.7 Principal Crops Grown in the Kabul River Basin | |
|---|---|
| Summer | Vines (grapes), vegetables, melons, maize, rice |
| Winter | Wheat, barley, pulses |
| Annual | Alfalfa, clover |
| Perennial | Orchard crops (apples, pistachios, almonds, walnuts, apricots, pomegranates), mulberry |

*Source: Montreal Engineering Company 1978, Vol. I, section 2.6.*

east of Kabul (37,330 hectares) would have to be irrigated with reclaimed wastewater and drainage from Kabul. However, as Kabul presently has virtually no stormwater or sanitary sewers, this area is unlikely to be developed on that basis. Hence, the more practical estimate for the total area in the basin to be irrigated is 314,670 hectares.

# 3

# Strategic Development Issues in the Basin

## Development Needs in the Kabul River Basin

More than 25 years of war and civil strife in Afghanistan have resulted in widespread poverty and a breakdown in traditional social institutions. The vital traditional farmer-managed irrigation systems, which are the foundation of Afghanistan's agrarian rural society, have also been extensively damaged. Moreover, this period has had little development of infrastructure that could have utilized the rich endowment of water resources in the Kabul River basin.

Fifty-nine percent of the population of the basin is rural and lives outside Kabul; more than 96 percent live in small villages and settlements, primarily along the rivers in cultivable areas with access to water. Rain-fed agriculture is only approximately 3 percent of the total cultivated area in the basin. Jalalabad is the only other large city in the Lower Kabul subbasin, with a population of approximately 120,000, while the remaining 30 towns in the basin average a few thousand.

Rebuilding rural community social capital and restoring damaged irrigation infrastructure has been a high priority of the government over the past five years. Despite some success, however, there has not been any investment in infrastructure that would (a) free farmers from the constraints of low volume and highly variable streamflow in the growing season; (b) reduce the impact of frequent drought and fickle rain; and (c) provide them with a base from which they could integrate with the country's growing economy, breaking out of persistent poverty.

Livelihoods in rural Afghanistan and the Kabul River basin rest on the exploitation of local natural resources, including soil, water, forests, and grazing areas. The lack of alternative sources of fuel, especially for cooking and heating in the cold winters, and unregulated commercial exploitation, has resulted in widespread deforestation of the basin. The breakdown of traditional practices that protected watershed areas with their critical grazing and water harvesting catchments led to the loss of village resources, including grazing lands and drinking and livestock water supplies. As a result village water supplies are tied ever more tightly to the traditional canal systems and are hence subject to the high variability of streamflows and frequent drought.

Electricity is vital to both economic development and agricultural growth. The electricity supply system was damaged extensively during the long period of war and civil strife. The lack of maintenance and nonavailability of spares led to deterioration in machinery and production. Little investment was undertaken in transmission and distribution systems. At present there is an installed capacity of approximately 377 megawatts, of which 70 percent is provided by hydroelectricity, with over 80 percent located in the Kabul River basin. The present generating capacity is considerably lower than the installed capacity but the government is implementing a priority program of repair and renewal to increase capacity and production. Nevertheless, current production is less than the estimated demand from presently connected customers (Toosab and RCUWM 2006) and current unfulfilled demand is more than twice the current energy availability. The government has been filling supply gaps with extremely expensive diesel generation, and is importing electricity from Uzbekistan, Tajikistan, Turkmenistan, and the Islamic Republic of Iran. Just as the uncertain and inadequate water supply constrains investment in high-value agriculture and agribusiness, so will inadequate and unreliable energy supply constrain the government's efforts to promote industrial investment and employment growth. Hence, a low-cost, reliable, and long-term sustainable supply of electricity is vital to achieving the government's development goals.

Lack of electrical energy and drinking water supply are not just technical or economic problems – they also represent major social and political problems. The lack of energy in winter for lighting and heating causes major suffering and social tension. The lack of drinking and domestic water, especially in urban areas, is a major public health problem. Domestic water supply systems have also long experienced low levels of investment and maintenance, which have reduced service coverage and quality to levels that are among the lowest in the world. In Kabul, a major city and one of the fastest growing in Asia, present water production per capita is approximately 16 liters per person per day and is declining (Beller Consult, Kocks, and Stadtwerk Ettlingen, 2004). Kabul's limited water distribution network and unreliable supply has necessitated reliance on unsafe shallow groundwater and expensive tanker supplies for large numbers, including many who moved from impoverished rural areas for work and are unconnected to the water distribution network.

## Resource-Based Economic Growth

Since 2002, one cornerstone of the government's development and poverty reduction strategies has been the development of the natural resources in the Kabul River basin and other river basins. Building on its increasingly successful short-term strategy of rehabilitating traditional irrigation schemes, the government is anxious to move forward with its longer-term investment strategy for larger-scale water management infrastructure. This is targeted to overcome the constraints of inadequate and unreliable water availability and frequent drought and provide a basis for sustained economic growth.

The Kabul River basin comprises neither the largest nor the most important agricultural area in the country. Afghanistan's northern region, in the Amu Darya basin, is a far larger agricultural area in terms of existing development, production, and future potential. Nevertheless, agricultural development areas in the Kabul River basin have historically been prime areas of high-value horticulture. They are close to the major markets in Kabul that are likely to attract early investment in agribusiness. They lie astride the major road network that efficiently links them to Afghanistan's primary international airport and with Pakistan and other export markets. The Kabul River basin is therefore also a priority for early and major investment in irrigated agriculture.

There are ample water resources available to achieve this goal. The average flow of the Kabul River basin (see table 2.1) is 8 times the total water required, at the point of diversion, if all the area of approximately 352,000 hectares (see table 2.6) is irrigated at an overall efficiency of 45 percent. This works out to over 5 times the water required at an efficiency of 30 percent, which is closer but probably higher than the current value. Even in the smaller Panjshir subbasin (see figure 2.3), the average flow is nearly 5 times the water required at an efficiency of 45 percent and approximately 3 times that required at an efficiency of 30 percent. While such comparisons are useful for having a sense of the relative magnitude of supply and demand, it does not follow that it is possible to allocate this amount of water to agriculture in the months when it is needed and still meet other demands on the source.

The Kabul River basin also has very advantageous topography for the development of water storage projects. The upper Panjshir River passes through a steep gorge to the Shomali Plain, where it joins the smaller Ghorband River (see figure 2.3), and then flows through a second steep and narrow gorge (see figure 2.4) before joining the Kabul River. Similarly, after the confluence of the Upper Kabul and Panjshir rivers, the Kabul River flows through a gorge until its valley widens considerably just upstream of Jalalabad in Nangarhar Province. The Konar and Laghman rivers, major tributaries of the Lower Kabul River, have similar favorable topography. Two thirds of the existing hydroelectric capacity developed in the Kabul River basin lies in the Lower Kabul River gorge above Jalalabad. Along the Panjshir and Lower Kabul rivers, as well as the major tributaries of the Lower Kabul River, the Laghman and Konar, approximately ten favorable dam sites with substantial storage and hydroelectric capacity have been identified and studied at reconnaissance and prefeasibility levels, mostly in the early and late 1970s. The

| Table 3.1 Kabul River Basin Water Supply and Demand Balance | | |
|---|---|---|
| | Kabul River at Dakah | |
| | with Konar subbasin flow | without Konar subbasin flow |
| | $Mm^3$/year | |
| Average annual water supply | 19,206 | 5,224 |
| Basin bulk water demands | 3,874 | 2,901 |
| Urban and rural drinking | 401 | 401 |
| Environmental flow requirement | 41 | 41 |
| Mining | 43 | 43 |
| Irrigation | 3,389 | 2,216 |

topography of the Logar and Upper Kabul rivers above Kabul is more variable but favorable for smaller dam sites that have also been identified in these valleys.

## Overall Balance of Bulk Water Supply and Demand

Table 3.1 summarizes the overall balance of bulk water supply and demand in the Kabul River basin. Ample water appears available to meet foreseeable bulk water demand even if the flow of the Konar River subbasin is not considered. This aspect is important as nearly three quarters of the bulk water demands occur in the basin upstream of where the Konar River joins the Kabul River. This confluence is approximately 60 kilometers upstream of the Kabul River's entry into Pakistan. The average annual flow of the Konar River is approximately two thirds of the flow of the Kabul River into Pakistan.

The apparent surplus of water availability over bulk water demand (table 3.1) masks important disparities and difficulties at the subbasin level. In the Logar-Upper Kabul subbasin, aggregate bulk water demand is more than twice the total average annual water availability. In contrast, aggregate bulk water demand is just over one third the total average annual water availability in the Panjshir subbasin. However, unlike the Logar-Upper Kabul, the Panjshir has important hydroelectric power potential, and, as discussed in the next section, this will require substantial nonconsumption water demand in the form of regulated monthly flows.

The estimates and projections of bulk water demand (table 3.1) are based on the following factors:

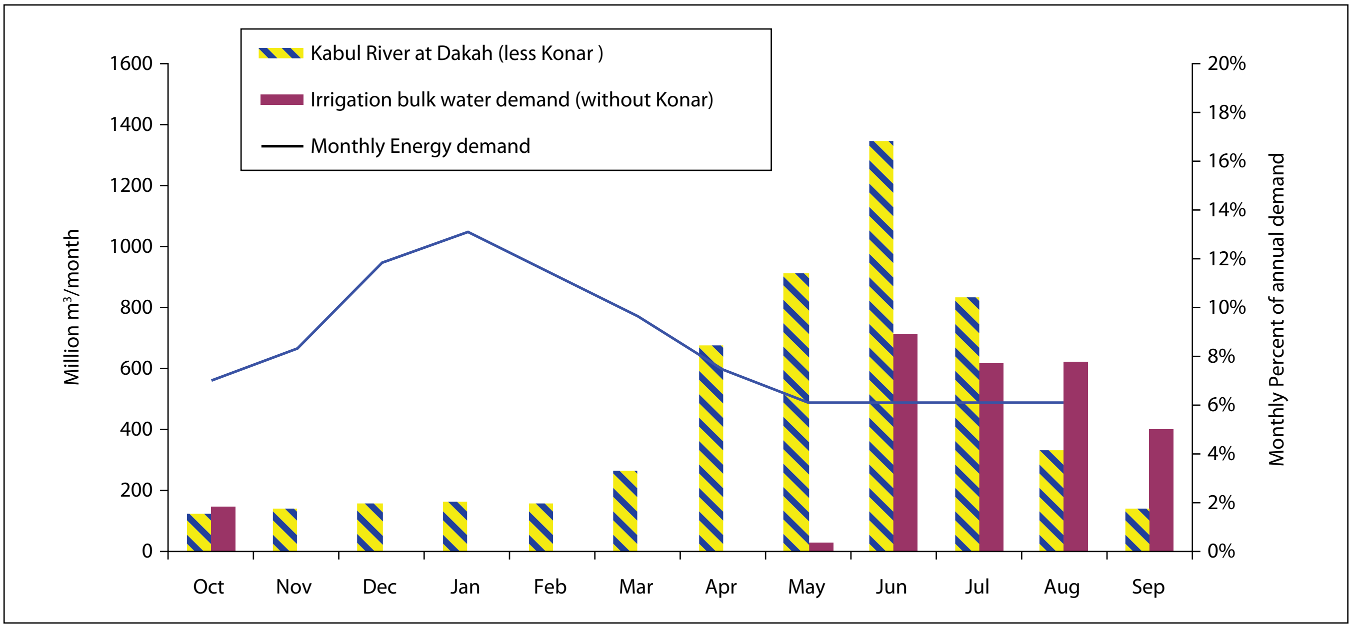
- Kabul's projected population of 8 million and approximately 6.5 million in the rural areas of the basin;
- Environmental flow requirements for a minimum flow of 1 cubic meter per second through Kabul and water required to make up net water losses due to evaporation from the Kole Hashmat Khan Waterfowl Sanctuary (1000 ha) near Kabul;
- Estimated water requirements when the Aynak copper mine facility is at full production (approximately 4 times the initially contracted requirement);
- Bulk water supply required to irrigate approximately 265,000 hectares[7] at an overall efficiency of 35 percent with current cropping patterns.

## Storage Development for Multiple Purposes

Although water resources in the Kabul River basin are substantial, their development presents some important challenges. Figure 3.1 shows the relationship between average monthly flow of the Kabul River basin, at the most downstream gauge at Dakah just before the river enters Pakistan, and the irrigation requirements and monthly pattern of energy demand. Note that in figure 3.1:

[7] This total is lower than that in table 2.6 on account of the area east of Kabul. This area is assumed to be only irrigated with reclaimed wastewater from Kabul that is expected to be available sometime in the future. The area irrigated would thus depend on the magnitude of bulk water supply to Kabul and the extent of sewer and wasterwater treatment coverage.

**Figure 3.1:** Average Monthly Flow in the Kabul River Basin (Without Konar River) vs. Energy Demand (% of Annual) and Irrigation Bulk Water Demand




- The average monthly flow of the Lower Kabul River at Dakah, upstream of where the Kabul River crosses into Pakistan, has been reduced by the average monthly flow from the Konar River watershed that joins the Lower Kabul River above the Dakah gauging station.

- The total irrigation diversion requirement at an overall efficiency of 30 percent is reduced by the diversion requirement for 22,000 hectares that can be served directly from the Konar River, this area lying along its narrow valley to the plain where the two rivers join.

- Energy demand is represented by monthly demand as a percentage of annual peak demand, that is, by the *shape and pattern* of demand rather than monthly energy demand or quantity of water.

- Kabul's urban domestic and industrial water demand, including the new copper mine and processing facility at Aynak, and environmental flows in the Upper Kabul River, both in the vicinity of Kabul, are substantial but small fractions of demand for energy and irrigation, and hence are not represented in figure 3.1 for the overall pattern of water supply and demand in the basin.[8]

Two points are noteworthy about the situation depicted in figure 3.1:

- The total diversion of water required for irrigating the area shown in table 2.6 (less the area served from the Konar River) exceeds the flow in the Kabul River basin in three of the five primary months of the irrigation season. Hence, storage is required to meet this diversion requirement. However, the amount of water actually allocated to these irrigation demands would depend on the cost and economic value of water in this use in comparison with others. If irrigation efficiency is improved to 45 percent, the requirement in the peak month of June can be reduced by approximately one third, but the situation depicted in figure 3.1 will still prevail. Not accounted for in this figure are the return flows from irrigation, namely

[8] If one looks in more detail at the relationship between water supply and demand in a particular subbasin, in particular the Logar-Upper Kabul subbasin, these aggregate urban, mining, and environmental water demands are the dominant water demands and substantially affect the relationship between water supply and demand and the infrastructure options that are important there. However, the precise relationship within the Logar-Upper Kabul subbasin emerges only from the analysis of all supply options and water demands in the Kabul River basin.

surface runoff and seepage of excess irrigation water that returns to the river system.[9] These return flows are substantial in part because of the cascade nature and lack of flow controls in most traditional systems, but also because of proximity to the river and the coarse, well-drained soils in many river valleys. Assuming an efficiency of 80 percent at the farmgate to account for nonbeneficial evapotranspiration, the total evapotranspiration is just 35 percent of the diversion requirement at an overall efficiency of 30 percent. These return flows (as high as 65 percent of water diverted after local use of groundwater recharged by seepage) would have a substantial positive downstream impact on supply, assuming that water quality does not deteriorate seriously.[10]

- The peak month for production of hydroelectric energy is January. The winter heating and lighting season extends from December to March. Releases from reservoirs with installed hydroelectric capacity would generally follow this pattern, especially so long as hydroelectric capacity is the dominant component of the electricity generation system. The winter season corresponds to the low flow months in the Kabul River basin. Hence, water would normally be stored (net of required releases for generation) in the higher flow months (April to August) so as to generate electricity in the winter. These months, however, are the same months in which releases and withdrawals would normally be made for irrigation.

The total storage capacity identified in the Kabul River basin is approximately 3,309 million cubic meters, without accounting for the major storage site on the Konar River, which is an additional one third of this. This represents approximately 63 percent of the average annual flow of the Kabul River at Dakah minus the Konar River streamflow. This suggests that (a) given economic and financial feasibility, it may be possible to develop sufficient storage to meet these two major water demands that occur in conflicting seasons, with sound management of reservoir operations; and (b) at the feasible ultimate level of development, there may also be storage capacity to carry over water from one year to the next to further reduce the impact of drought, if this is hydrologically and economically feasible. Notwithstanding these options, the amount of water that can be consumed in the Kabul River basin may ultimately be limited by the amount of water that is agreed for release downstream for Pakistan's use.

## Displacement of People and Resettlement

The construction of dams and reservoirs usually requires significant land acquisition in the reservoir areas, along with the resettlement and rehabilitation of the population and their economic assets displaced due to the project. In addition, there is potential for significant impacts on environmental and cultural assets present in the area. It is clear that a number of dams being considered in this study will involve significant displacement of people. For most of the dams, there are no known ecological resources such as wetlands or cultural resources in the potential reservoir areas. In the Panjshir and Lower Kabul subbasins, however, it is likely that some reservoirs would inundate forested lands.

While determining the cost of storage options, account must be taken of the cost of resettlement and economic rehabilitation of the displaced population including their lost assets, livelihoods, and public infrastructure. These costs will differ between storage options because of local conditions, but in most cases they will comprise a major part of the cost of storage development. This is particularly important in Afghanistan, where the rural population and agricultural activities are usually located along the river valleys close to the river, and where people have already suffered a long period of social disruption and displacement.

Data on these important impacts generally do not exist, and were unavailable for this study. These data could be readily incorporated into the DSS by undertaking a study to identify the land, population, economic, and social assets, and infrastructure that could be impacted by each dam, considering different heights up to the maximum potential for the site, and deriving two curves, namely (a) agricultural land lost versus dam height, and (b) total population impacted versus dam height. The latter could be converted

9 Irrigation water demand is the sum of the beneficial (consumed by the crop) and nonbeneficial (for example water evaporated from the soil surface) evapotranspiration. A quantity of water in addition to the crop water consumption is diverted and conveyed to the farmer to account for seepage and other consumption (and leaching where soil salinity is a problem) between the river or reservoir (or borehole) and the farmer. But a part of this extra water returns to the river or groundwater aquifer where it is available for other uses. Water that does not return to the hydrological system becomes a part of the nonbeneficial consumption.

10 This would be the case, for example, where soil and groundwater salinity are problems. This is unlikely to occur except in the very arid parts of the country.

| Table 3.2 Low Flows as a Percentage of the Mean Annual Flow | | | |
|---|---|---|---|
| **Low flow period** | **Return period** | | |
| | **5 years** | **10 years** | **20 years** |
| **Gulbahar on Panjshir River** | | | |
| 1 year | 81% | 73% | 65% |
| 2 years | 85% | 77% | 71% |
| 5 years | 90% | 87% | 83% |
| **Tangi Gharu on Upper Kabul River** | | | |
| 1 year | 63% | 53% | 46% |
| 2 years | 70% | 61% | 54% |
| 5 years | 79% | 71% | 65% |

*Sources: Toosab and RCUWM 2006, and mission estimates.*

to costs by multiplying with the average resettlement and rehabilitation cost, and the former evaluated at the average return per hectare for irrigated agriculture as determined in the model scenario. To these would have to be added the cost of replacing economic and social assets. High priority should be given to obtaining estimates of these critical data for each of the storage options.

## Streamflow and Rainfall Variability

The discussion in the previous section is based on average annual streamflows. Afghanistan is a drought-prone country and basin planning based solely on average streamflows leaves the development open to excessive risk. The DSS modeling tools used in this study directly consider the characteristic seasonal variations in streamflow and rainfall (chapter 2). The interannual variability of water, that is the variation in streamflow and rainfall from year to year, also needs to be incorporated in the analysis to ensure that choices between options explicitly reflect the different levels of interannual hydrological risk.

## Interannual Streamflow Variability

An example of the magnitude of streamflow variability in the Kabul River basin is summarized in table 3.2 and in figure 3.2. Table 3.2 summarizes an analysis of low flows at two stations in the Upper Kabul River basin – at Gulbahar on the Panjshir River, upstream of where it is joined by the Ghorband and Salang rivers (see figure 2.3), and at the Kabul River station at Tangi Gharu, downstream of where the Logar River joins the Upper Kabul River below Kabul.

Figure 3.2 shows the average flow for different low flow periods ranging from five months (or one irrigation season) to seven years, as a percentage of the long-term average flow for four different return periods at the Gulbahar station on the Panjshir River. Table 3.2 summarizes these data for three lean periods, namely one year, two years, and five years for three return periods, starting from 5, 10, and 20 years for both the Gulbahar station and the station at Tangi Gharu on the Upper Kabul River below the confluence with the Logar River (see figure 2.3).

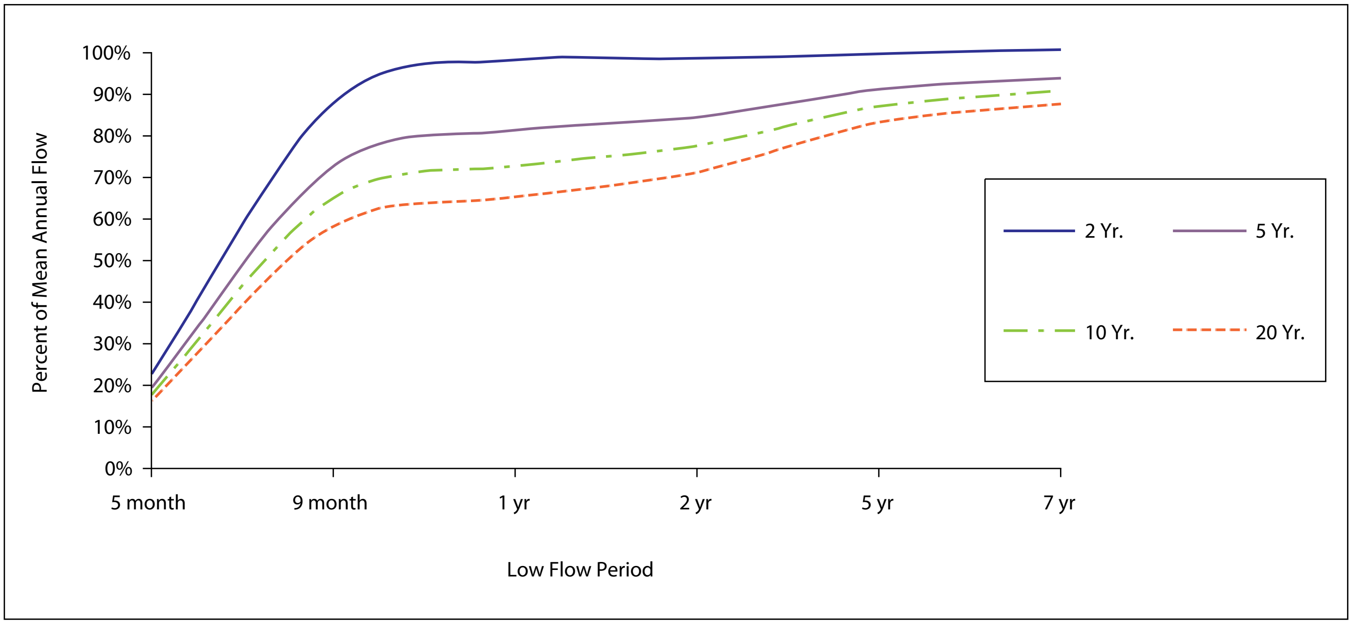
The variability of streamflow at Tangi Gharu, as measured by the coefficient of variation (CV),[11] is 40 percent, twice the value at Gulbahar (20 percent). The variability of flows of the Kabul River at Dakah is similar to Gulbahar but that is due to the much lower variability of flows in the Konar River, at approximately 13 percent.

In both figure 3.2 and table 3.2, as the return period is lengthened, that is as the probability of lower flows decreases, the departure from the mean annual flow during the indicated low flow period increases, in other words, the severity of the drought increases. For the 10-year return period (that is, 90 percent of the time the flow during the corresponding period would be greater) – a degree of risk commonly used in high value irrigation planning[12] – the average streamflow at Gulbahar is about 73 percent of

[11] The ratio of the standard deviation to the mean: a record with a lower value means that the flows are more closely clustered around the mean value than a record with higher value.

[12] There is often a much greater level of risk used in irrigation planning, perhaps 75 percent, typically in cases where irrigated farming is expected to use low cash inputs and low technology. In cases where high-value crops that commonly use high cash inputs and technologies are an important or even dominant part of the cropping pattern (as in large parts of the Shomali Plain in the Panjshir subbasin), the risk should be much lower to avoid potentially devastating financial losses.

**Figure 3.2:** Frequency and Magnitude of Low Flow Periods at Gulbahar on Panjshir River




the mean flow for a one-year low flow period or drought, and 77 percent for a drought that extends over a two-year period. There are over 70,000 hectares of potentially high-value agricultural land downstream to be served in part from this flow. For a 20-year return period (that is, with a probability of 95 percent), the lean period flows extending over one year and two years are 65 percent and 71 percent, respectively. Roughly speaking, in a 20-year return period drought year, there is a 5 percent chance that the flow will be approximately 25 percent below the average.

The severity of low flows or drought flows at Tangi Gharu, and hence in the Logar and Upper Kabul rivers, is consistently greater (table 3.2) for equivalent return periods or probabilities. In a drought year for the same 10-year return period, the one-year low flow is roughly half of the mean annual flow. The more rain-dependent watersheds in the Upper Kabul subbasin show a much greater departure from the annual mean flow under drought conditions.

The performance of the storage system, and the extent to which demands can be satisfied at an acceptable degree of reliability, need to be tested against these drought conditions that represent different degrees of risk. The effect of this variability on planning is to influence the planner to develop greater levels of storage to reduce the risk of shortage. The occurrence of these drought conditions can only be partially mitigated by storage, and their severity will have different economic impacts in each sector because the degree to which different sectors are able to adapt to low water availability is different.[13]

The aim in planning is therefore to devise a supply system that can be operated in a manner that results in the lowest acceptable risk (that is, the greatest possible reliability), and which is economically and financially feasible. The design of the systems to use the water resources should then incorporate measures to adapt to the level of risk that the system entails, so as to enable farmers and electricity and water customers to adapt and minimize damages and losses.

## Potential Climate Change Impacts

Regional climate models suggest that in general for the arid regions of Central and South Asia, the average annual temperatures would rise and the average annual precipitation would decrease (Ragab and Prudhomme 2002). This would mean that, on the one hand, average annual river flows can be expected to decrease, and, on the other hand, the crop water requirements and other associated demands would increase as a result of higher temperatures. No specific

[13] This includes the disincentive to invest in activities that depend significantly on water supply (as also the quantity, reliability, and cost).

studies have been carried out to estimate the impacts of climate change in the main river basins of Afghanistan; therefore quantitative data are not available. However, as described before, the DSS is structured to retain the ability of analysis for different overall volumes and patterns of streamflows as well as basin water demands.

## Urban Domestic and Industrial Water Supply

As noted in section 3.1, the second major issue that needs to be addressed in developing the Kabul River basin is rural and urban water supply. Rural water supply requirements are widely dispersed, but will generally total in the aggregate about 1.5 percent or less than the total water available in the basin, without considering the Konar River flows. If this volume of water is accounted for in each subbasin and watershed, and not allocated to some other use, access to safe drinking water in rural areas in line with the Millennium Development Goals (MDGs) will essentially involve the design and implementation of sustainable programs that reach the thousands of small villages and settlements in the 101 districts in the basin.

Urban water supply for domestic and industrial use presents a different challenge. There are only two significant demand centers in the basin, namely Jalalabad (with a population of approximately 120,000 and a very small distribution network) and Kabul. For this study, the future water demands for Jalalabad as well as for other small towns in the basin have been included in the estimate of rural water demands. Kabul, the economic and administrative center of the country, is growing extraordinarily fast, and its present supply is totally inadequate. Moreover, as discussed below, the estimated water production requirement of Kabul in 2020 will be equivalent to approximately 37 percent of the total average annual flow of the Logar-Upper Kabul subbasin in which it is located.

**Table 3.3 Kabul Population Forecasts**

| Year | Population |
|---|---|
| 2005 | 3,042,447 |
| 2010 | 3,527,525 |
| 2015 | 4,088,775 |
| 2020 | 4,739,000 |

*Sources: Beller Consult, Kocks, and Stadtwerk Ettlingen 2004, Interim Report; and mission estimates.*

### Forecasts of Demand for Kabul Bulk Water Supply

The lack of reliable data has made estimates of the present population of Kabul difficult. This has been made more problematic by the return of a large number of displaced persons to the country since 2002, by the displacement of many people by the severe drought during 1999–2002, and by the widespread poverty, high unemployment, and lack of opportunity in rural areas. Table 3.3 summarizes the Kabul water supply feasibility study (Beller Consult, Kocks, and Stadtwerk Ettlingen 2004) estimates of population in 2005, 2010 and 2015, which are based on a detailed reconciliation of Central Statistical Office estimates, district population estimates within the city, and an assumed natural growth rate of 3 percent. These figures were extended in the present study to 2020 (table 3.3) at the growth rate assumed by the consultants.

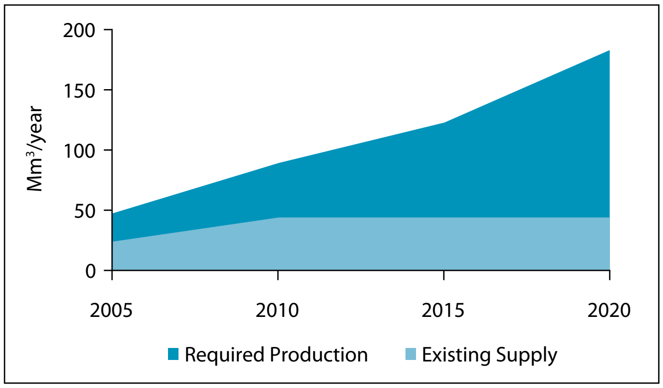
Table 3.4 summarizes the Kabul water supply feasibility estimate of annual water production requirement, based on the above population forecasts, and extended in this study to 2020. The population includes those not connected, and

**Table 3.4 Forecast of Required Water Production for Kabul**

| | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|
| Domestic bulk water requirement (Mm$^3$/yr) | 23.2 | 51.2 | 77.7 | |
| Commercial, administration, industry (Mm$^3$/yr) | 5.1 | 12.9 | 21.0 | |
| Total annual demand (Mm$^3$/yr) | 28.2 | 64.1 | 98.7 | 147.0 |
| Losses as a percentage of demand | 68% | 40% | 25% | 25% |
| ***Total annual required production (Mm$^3$/yr)*** | ***47.5*** | ***89.7*** | ***123.4*** | ***183.8*** |
| Implied average rate of consumption (liters per capita per day) | 42.8 | 69.7 | 82.7 | 85.0 |

*Sources: Beller Consult, Kocks, and Stadtwerk Ettlingen 2004, Interim Report; and mission estimates.*

**Figure 3.3:** Required Kabul Water Production and Existing Supply (based on Short Term Program)




those in villas, flats, and existing and new quarters. The assumed consumption in 2015 ranges from 50 liters per capita per day for household connections with traditional sanitation, which is predominant in Kabul, to 125 liters per capita per day for block and flats and 150 liters per capita per day for high-standard villas. Losses as a percentage of production are projected to decline from 40 percent in 2005 to 29 percent in 2010 and to 20 percent in 2015.

## Kabul's Strategic Problem

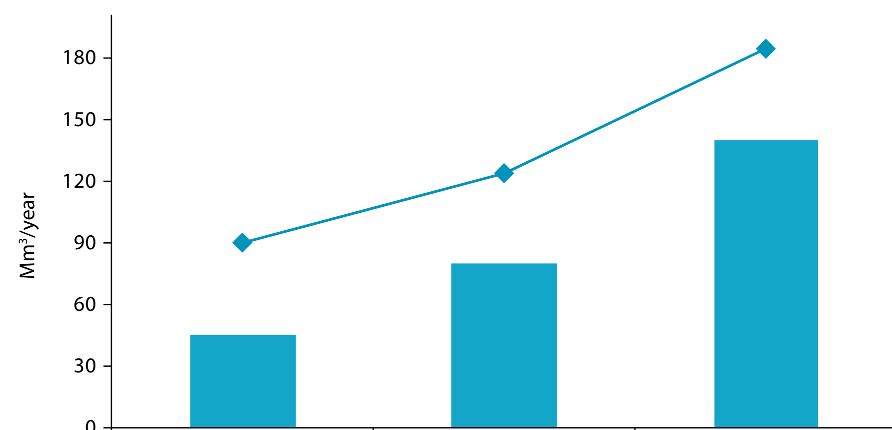
The water production required over the period 2005–2020 and the available supply after completion of the ongoing Short-Term Program (Beller Consult, Kocks, and Stadtwerk Ettlingen 2004) in 2010 is shown in figure 3.3. A substantial gap will exist even after the Short-Term Program is completed, and this will grow steadily into the future without a major increase in supply. Without implementation of a long-term program and the addition of new sources of supply, per capita production will fall below 2010 levels in 2015, continuing steadily downward thereafter.

The production capacity or supply needed in 2010 and beyond is summarized in figure 3.4. The gap in 2010 is about 45 million cubic meters, roughly equal to the maximum supply from existing sources. This gap grows to approximately 79 million cubic meters in 2015. The incremental supply needed to keep pace with the growth of demand between 2015 and 2020 is an additional 60.4 million cubic meters per year.

## Environment

There are two important environmental flow requirements in the basin. The first concerns the maintenance of the Kole Hashmat Khan Waterfowl Sanctuary, an important historical and cultural site and a major environmental resource directly adjacent to the city, which has long suffered from neglect, overharvesting of reeds, and encroachment by nearby farmers and new housing

**Figure 3.4:** Incremental Bulk Water Production Required to meet Kabul Requirements




| | 2010 | 2015 | 2020 |
|---|---|---|---|
| Required Incremental Supply | 45.2 | 78.9 | 139.3 |
| Required Production | 89.7 | 123.4 | 183.79 |

development. It was an important resting and nesting site for migratory waterfowl until water levels dropped dramatically in recent years. To maintain the wetland, an allocation of streamflow from the lower Logar River will be sufficient to overcome the precipitation-evapotranspiration deficit that occurs from April to November.[14] In an average year, the estimated total deficit is approximately 9,467 cubic meters per hectare. Annual water requirements would be 1.89 million cubic meters per year for a 200-hectare wetland, and 9.47 million cubic meters per year for a 1,000-hectare wetland.

The second important environmental flow requirement is the need to maintain sufficient low flow in the Kabul River as it passes through the city. In recent years, this flow has reduced to an insignificant trickle in the low flow months. The consequence is that untreated wastewater and trash accumulates in the river channel during the summer months, causing noxious odors and health hazards. In the absence of any studies to determine what the range of minimum flow values should be, the model includes an option to set the minimum required flow through the city to a desired level, and in the Base Case scenario this flow is set to an arbitrarily selected placeholder value of 1 cubic meter per second, which is likely to be found to be too low. The purpose of using a placeholder value is to illustrate how such environmental flow targets could be included into basin development planning. The values can be revised as additional detailed studies are conducted on environmental flow requirements in the basin.

# Basin Planning and Management Objectives

In general, a planning process begins by establishing planning objectives and criteria as part of a structured stakeholder consultation process. The consultations include discussions with stakeholders, policy makers, and water users across all sectors on identifying the issues that need to be addressed, development needs and opportunities, and stakeholders' vision of the future of the basin. The articulated vision and goals are then translated into specific development objectives and criteria, which enable the assessment of various options and scenarios.

[14] This is a crude approximation of the water required to maintain the wetland. Typically, the attempt would be to maintain the annual hydrology.

Such a process was not undertaken as a part of this study given the current constraints of working in Afghanistan. However, under the proposed new Water Law, approved by the Cabinet and presently before the Parliament, basin and subbasin councils of stakeholders will be established in each river basin to provide a mechanism for stakeholder input in the basin planning process. Nevertheless, based on the government's series of national development strategies prepared since 2002 and other discussions with officials, an example of how such a basin vision, planning objectives, and criteria might look for the Kabul River basin is outlined below.

## Envisioning the Future of the Kabul River Basin

A structured stakeholder consultation is a process that seeks to elicit the views of a broad cross-section of stakeholders in the context of a common understanding of where the basin is today and where they want it to be in the future. A simplified example of the outcome of such an exercise is presented in box 3.1. The various dimensions of the vision encompass all sectors and the economic, social, and environmental aspirations of stakeholders.

## Translating the Basin Development Vision into Objectives and Criteria

The vision of the basin's future developed above would need to be translated into objectives, criteria, and specific, quantifiable indicators that can be used to examine and evaluate alternative planning scenarios, options, and plans. An example is given in the consequence table (table 3.5), which is derived from the preliminary vision for the Kabul River basin in box 3.1. The objectives have been framed in four development areas, namely economic, social, environmental, and institutional.

The aim is to ensure that the criteria refer to final objectives and goals, and are not focused on intermediate outputs or on the means for achieving the goals. Alternative means or options would be evaluated against the objectives criteria. The indicators should be comprehensive across objectives and criteria to be considered in decision making, as well as limited in number to enable

**BOX 3.1** Envisioning the Future of the Kabul River Basin: The Ideal Kabul River Basin in 20 Years

- Reliability of agricultural water supply is increased and drought vulnerability is decreased in existing and new areas of irrigated agricultural development
- Sufficient hydropower generating capacity is developed to ensure that demand in the basin is fully met in all seasons
- Domestic users and industry in and around Kabul have secure access to safe, reliable, and adequate water supply for future needs
- All rural households have improved access to a secure and safe drinking water supply
- Increased agroprocessing investment, coupled with an improved all-weather road system, gives farmers improved access to markets and higher-value options
- No water quality problems emerge as a result of urban and industrial growth in water use and adequate environmental flows are maintained
- Well-managed watershed areas are productive and environmentally protected, and the quality of livestock grazing is improved, groundwater recharge is improved, and soil erosion is minimized
- Development activities are socially, environmentally, and economically sound
- Food security is achieved
- Decrease in poverty measured as per capita annual average income that rises from current levels to $ X per day

**Table 3.5 Consequence Table - Criteria and Metrics to Assess Scenarios Options**

| Type | Criteria | Indicator | Preference (H=higher is better L=lower is Better) | Units |
|---|---|---|---|---|
| Economic | Total Net Economic Benefits | Economic benefits less costs | H | million $/year |
| | Agriculture | Agricultural benefits | H | million $/year |
| | Power | Electricity Generation benefits | H | million $/year |
| | Agroprocessing | Value-added of agroprocesing in basin | H | million $/year |
| | Mining | Annual water supply matches production requirements | H | $Mm^3$ |
| | Employment | Total new full-time eq.jobs | H | million # jobs |
| Social | Poverty | Change in no. people above $1 ($5?)/day | H | million # people |
| | Resettlement | People relocated due to development projects | L | thousands # people |
| | Access to Water | % of rural population with access to safe drinking water | H | % |
| | Kabul water supply | Annual water production per capita | H | $Mm^3$/person |
| | Food Security | Number of food-insecure districts | L | number |
| Environmental | Environmental Flows | Flow in Upper Kabul River through City | H | $Mm^3$ during tourist season |
| | Wildlife Sanctuary | Resloration and maintenace of waerfow habital | H | Specie diversily (index, counts) |
| Institutional | Information | Reliable knowledge base (e.g. hydro-met) and tools | H | Scale (1–5) |
| | Financing Risk | Financing Risk Scale | L | Scale |
| | Technical Risk | Technical Complexity Scale | L | Scale |

meaningful interaction later when the consequences of various alternative plans are to be evaluated against these indicators.

An example of the use of a consequence table in the multicriterion evaluation of scenarios based on various combinations of options is discussed in appendix C. In the approach outlined therein, all scenarios and options are evaluated in terms of the appropriate measures for each criterion. The measures for these criteria are not all commensurate, that is, they do not all use the same metric (for example US$, hectares, and gigawatt-hours). In using the consequence table, all scenarios are evaluated against a chosen scenario until the most desirable scenarios are identified. It would be uncommon for one scenario to be better than all others with respect to all criteria. Hence, the final choice among the best scenarios (and the corresponding options and outcomes) will come down to identifying the most critical criteria on which the scenarios differ, and making decisions with explicit consideration of priority criteria. This analysis of tradeoffs is at the heart of multiobjective planning.

# 4

# Kabul River Basin Investment Options

## Introduction

The approach taken in this study is to

- identify the various options and opportunities for developing water resources in each subbasin, and identify all potential water demands by all sectors of activity;
- define each option and development opportunity or requirement in terms of its location and its physical and economic characteristics;
- define the water requirements and demands by each sector activity in each area.

These options, opportunities, and requirements are integrated in a mathematical model (described in chapter 5) designed to select and scale those options that satisfy the demands and requirements of all the sector activities with maximum net benefit. Hence, within the limits of water availability in the basin,[15] the model allocates water to sector activities in a way that maximizes total net economic benefit. The ensemble of these data, including information on the schematic structure of the basin and the linkage between the elements of the system, constitutes the knowledge base for the basin. This knowledge base, together with the model and the analysis of its outputs, constitute the Kabul River basin's Decision Support System (DSS).

[15] Water availability can be varied from scenario to scenario, including the mean annual flow and a range of drought conditions that are based on the analysis of the existing hydrological records (Toosab and RCUWM 2006).

## Storage Investment Options

The potential storage and hydroelectric power sites in the Kabul River basin are shown in the schematic diagram of the basin in figure 4.1. The principal characteristics of these storage sites are summarized in table 4.1. Storage-elevation-surface area and cost data for each storage site were taken directly from the *Kabul River Valley Development Project* (Montreal Engineering Company 1978, Vol. I, chapter 4). Costs were extrapolated from 1978 to 2004 using a gross domestic product (GDP) deflator of 2.37. These data are summarized in table 4.1.

The 13 sites shown in figure 4.1 are not exhaustive. These are the priority sites that were identified in earlier plans as having the most favorable storage cost characteristics; and they are the most significant sites in terms of power production or flow regulation. There are numerous small and medium reservoirs that have been identified and the Ministry of Energy and Water is presently studying some of these sites. If these prove viable, they could be added to this knowledge base and their effects on the overall water management plan for the basin studied. The sites described in table 4.1 provide in general terms the potential for a storage system in each subbasin and between subbasins, as well as the capacity for development of the overall basin.

| Table 4.1 Characteristics of Potential New Storage Sites in the Kabul River Basin | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Dam height | Gross storage | Live storage | Installed capacity | Annual cost | Capital cost | Annual unit cost of live storage |
| | | (m) | ($Mm^3$) | ($Mm^3$) | MW | (MUS$) | (MUS$) | ($/$m^3$) |
| **Panjshir subbasin** | | | | | | | | |
| Totumdara | R8 | 135 | 410 | 340 | na | 33.2 | 332 | 0.098 |
| Barak | R9 | 155 | 530 | 390 | 100 | 117.4 | 1,174 | 0.301 |
| Panjshir I | R10 | 180 | 1,300 | 1,130 | 100 | 107.8 | 1,078 | 0.095 |
| Baghdara | R11 | 40 | 400 | 330 | 210 | 60.7 | 607 | 0.184 |
| **Logar-Upper Kabul subbasin** | | | | | | | | |
| Haijan[a] | R12 | 50 | 220 | 200 | na | 7.2 | 72 | 0.036 |
| Kajab | R2 | 85 | 400 | 365 | na | 20.7 | 207 | 0.057 |
| Tangi Wardag | R4 | 65 | 350 | 300 | na | 35.6 | 356 | 0.119 |
| Gat | R7 | 20 | 500 | 440 | na | 5.1 | 51 | 0.012 |
| **Lower Kabul subbasin** | | | | | | | | |
| Sarobi II (ROR) | R16B | 200 | na | na | 210 | 44.2 | 442 | na |
| Laghman A | R17 | nd | 405 | 288 | 44 | 1,251 | 125.1 | 0.434 |
| Konar A | R19 | nd | 1,212 | 1,010 | 366 | 94.8 | 948 | 0.094 |
| Konar B (ROR) | R20 | nd | na | na | 81 | 23.2 | 232 | na |
| Kama (ROR) | R21 | nd | na | na | 60 | 11.5 | 115 | na |

*Notes: Costs are for full development of the site; ROR: run-of-river; na: not applicable; nd: no data*

***a:** Near the Shatoot site that is currently under study*

*Sources: Montreal Engineering Company 1978, Vol. I, chapter 4; Toosab and RCUWM 2006; and mission estimates.*

**Figure 4.1:** Kabul River Basin Storage Options

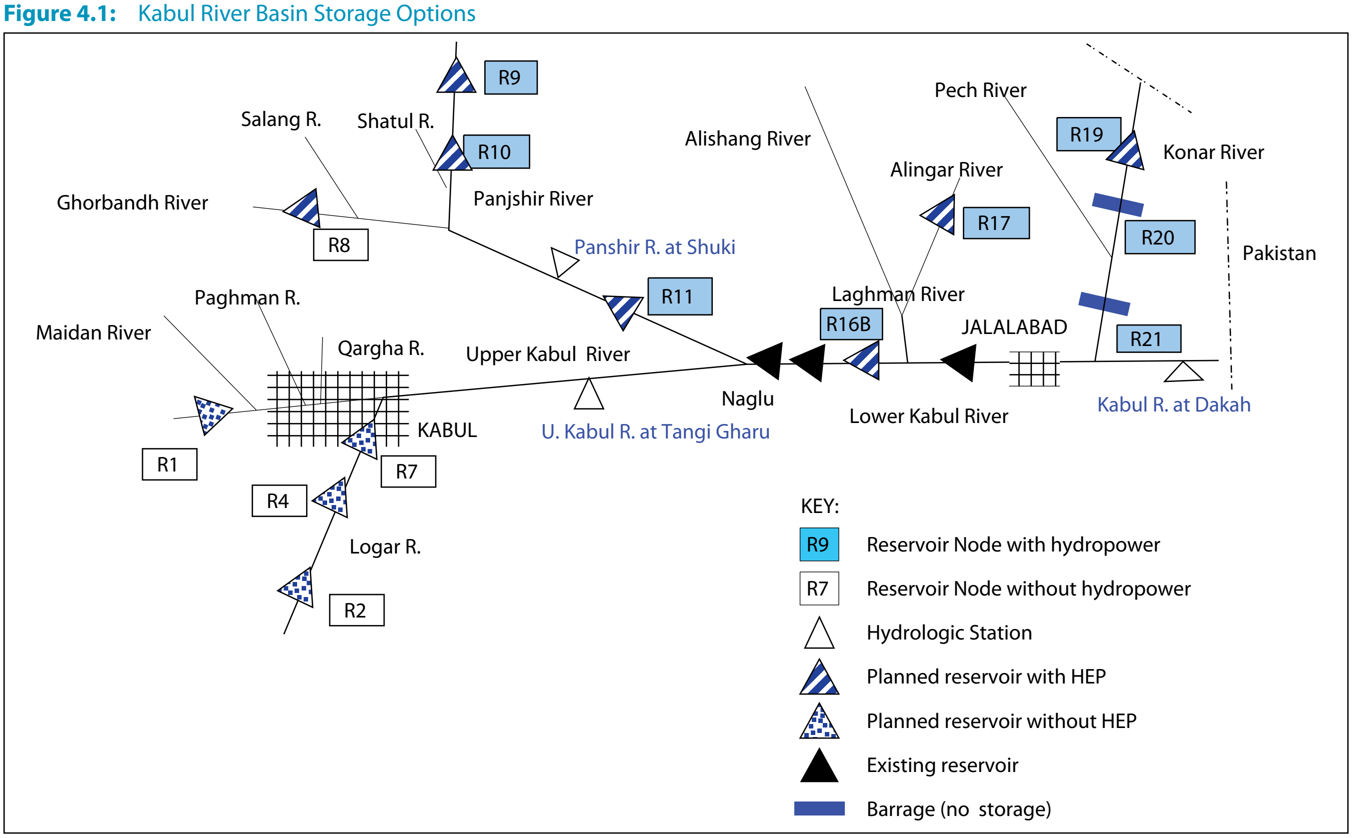


Table 4.2 High and Low Forecasts of Monthly Energy Demand in 2020 (Without export from or Import to the Basin)

| Year | Range | Annual hydropower energy demand (GWh) |
|---|---|---|
| | | Base estimate |
| 2020 | Minimum | 1,350.9 |
| | Maximum | 2,180.0 |
| 2015 | Minimum | 1,081.2 |
| | Maximum | 1,993.0 |
| 2006 | Minimum | 672.5 |
| | Maximum | 848.0 |

*Source: based on Toosab and RCUWM 2006.*

**Figure 4.2:** High and Low Forecasts of Monthly Energy Demand (2020 Without Exports or Imports)

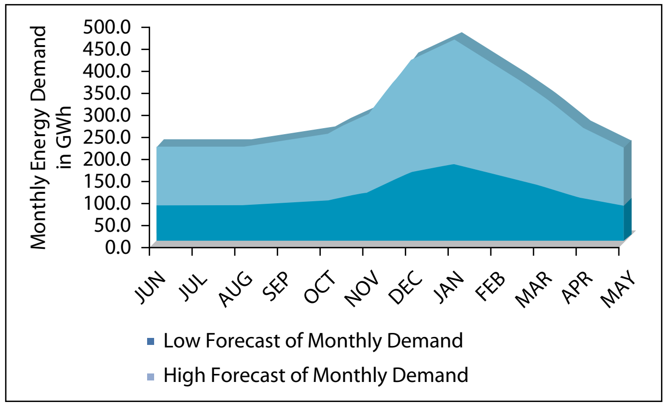



Table 4.3 Distribution of Monthly Energy Demand

| | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ratio of monthly to annual peak energy demand | 0.47 | 0.47 | 0.47 | 0.50 | 0.53 | 0.63 | 0.90 | 1.00 | 0.87 | 0.73 | 0.57 | 0.47 |
| Percentage of annual demand in the respective month | 6.1% | 6.1% | 6.1% | 6.6% | 7.0% | 8.3% | 11.8% | 11.4% | 9.6% | 7.5% | 6.1% | 6.1% |

*Sources: Toosab and RCUWM 2006, and World Bank estimates.*

## Hydroelectric Power Development Options

Figure 4.1 indicates which of the storage sites have hydroelectric generation potential,[16] and table 4.1 indicates the estimate of installed capacity at each site. Potential capacity totals an estimated 1,171 megawatts at eight sites, including 351 megawatts at three run-of-river sites.

Analysis of this hydroelectric generation potential depends on both the total annual energy demand and its monthly distribution. Forecasts of Kabul River basin energy demand (Toosab and RCUWM 2006) are summarized in tables 4.2 and 4.3. These are based on estimates of energy demand in the nine provinces covering the basin. Present demand (2006) is based on energy delivered to currently connected customers, projected growth of both electricity coverage and demand (primarily household in the short to medium term), and an estimate of presently unanswered demand. A range of demands representing the minimum and maximum forecasts for 2006, 2015, and 2020 is shown in table 4.2. The minimum and maximum monthly energy demand based on table 4.2 is shown in figure 4.2.

Provision has been made in the current study to augment the energy demands shown in table 4.2 by adding energy to be exported to other parts of Afghanistan or other countries (such as Pakistan), and to decrease basin demand by the amount of energy that may be imported from other regions or countries.

In a hydro system, the monthly distribution of energy demand is important as it determines how the reservoirs should be operated to meet demand. Table 4.3 summarizes the estimate of the monthly demand for energy. These data are derived from the Toosab and RCUWM (2006) estimate of the annual energy demand curve. The percentages shown in the table have been used to distribute the total annual energy demand from table 4.2 to each month (figure 4.2). The ratios have been used to determine the value of energy in each month in relation to the value of energy in the month of peak demand (January).

[16] Hydropower generation facilities might be added to the non-hydro sites identified in figure 4.1. This potential was not studied or costed in the past, and hence not incorporated in the current study.

Based on the 2020 minimum and maximum basin energy demand, without exports from or imports to the basin (table 4.2), the annual load factor is about 0.63. Applying this factor to the peak month of January, the estimated peak power requirements range between 510 and 825 megawatts.

## Irrigated Agriculture Development Options

The existing and potential irrigated areas in the Kabul River basin are shown in figure 4.3. The three largest areas are in (a) the Shomali Plain in the central Panjshir River basin, (b) the large plain near the Lower Kabul River in Nangarhar, and (c) along the Logar River. Fourteen individual areas or subregions were identified as agriculture water demand nodes[17] as summarized in table 4.4.

Table 4.5 summarizes the data for these areas, including crops, assumed initial cropping pattern, improved yield levels[18] with irrigation, and assumed net revenue per unit of output (measured as tons of crop sold). A comparison of the net return per ton of output of each crop, used in this study and in the earlier Toosab and RCUWM (2006) study, is shown in figure 4.4 in terms of the ratio to that of wheat.

**Table 4.4 Potential Irrigated Areas in the Kabul River Basin**

| Irrigated area | Node | Total area (hectares) |
|---|---|---|
| **Logar-Upper Kabul subbasin** | | |
| Chak-e-Wardak (Logar) | D2 | 3,750 |
| Tangi Wardag (Logar) | D4 | 26,000 |
| Gat (Logar) | D5 | 10,500 |
| Upper Kabul irrigation | D7 | 28,740 |
| East of Kabul (recycled wastewater) | D30 | 37,330 |
| **Panjshir subbasin** | | |
| Shomali Plain | D20 | 53,130 |
| Kapisa | D24 | 20,170 |
| **Lower Kabul subbasin** | | |
| Laghman and Alishang valleys | D37 | 16,400 |
| Konar River – Asmar hydrological unit | D38 | 4,140 |
| Konar River – Konari hydrological unit | D39 | 8,990 |
| Konar River – Kama scheme | D40 | 9,000 |
| Nangarhar (right bank of Kabul River) | D41 | 40,000 |
| Surkhand River valley | D42 | 22,000 |
| South of Surkhand valley | D43 | 36,000 |

*Sources: Montreal Engineering Company 1978, Toosab and RCUWM 2006, and World Bank estimates.*

**Table 4.5 Agriculture in the Irrigable Areas of the Panjshir Watershed**

| Crop | Assumed initial cropping pattern (%) | Improved yields (tons/ha) | Prices (2004) (US$/ton) |
|---|---|---|---|
| **Wheat** | 25 | 2.6 | 50 |
| **Maize** | 5 | 2.0 | 25 |
| **Rice** | | 3.0 | 150 |
| **Alfalfa** | 5 | 5.0 | 25 |
| **Vines/grapes** | | 8.5 | 125 |
| **Vegetables** | 35 | 18.0 | 65 |
| **Melons** | 5 | 12.0 | 65 |
| **Orchards** | 10 | 10.0 | 175 |
| **Cotton** | 15 | 1.4 | 65 |

*Note: The cropping pattern shown above is for the Panjshir subbasin. The initial cropping pattern in the other two subbasins is slightly different.*

*Sources: Montreal Engineering Company 1978, Vol. II, annex E; and mission estimates.*

The weighted average annual evapotranspiration on a hectare of land planted to the assumed initial cropping pattern (table 4.5) is about 5,113 cubic meters per hectare.[19] At the low irrigation efficiency (30 percent), the water diversion requirement is about 13,636 cubic meters per hectare and, at an improved efficiency of approximately 45 percent, the diversion requirement is about 9,131 cubic meters per hectare.

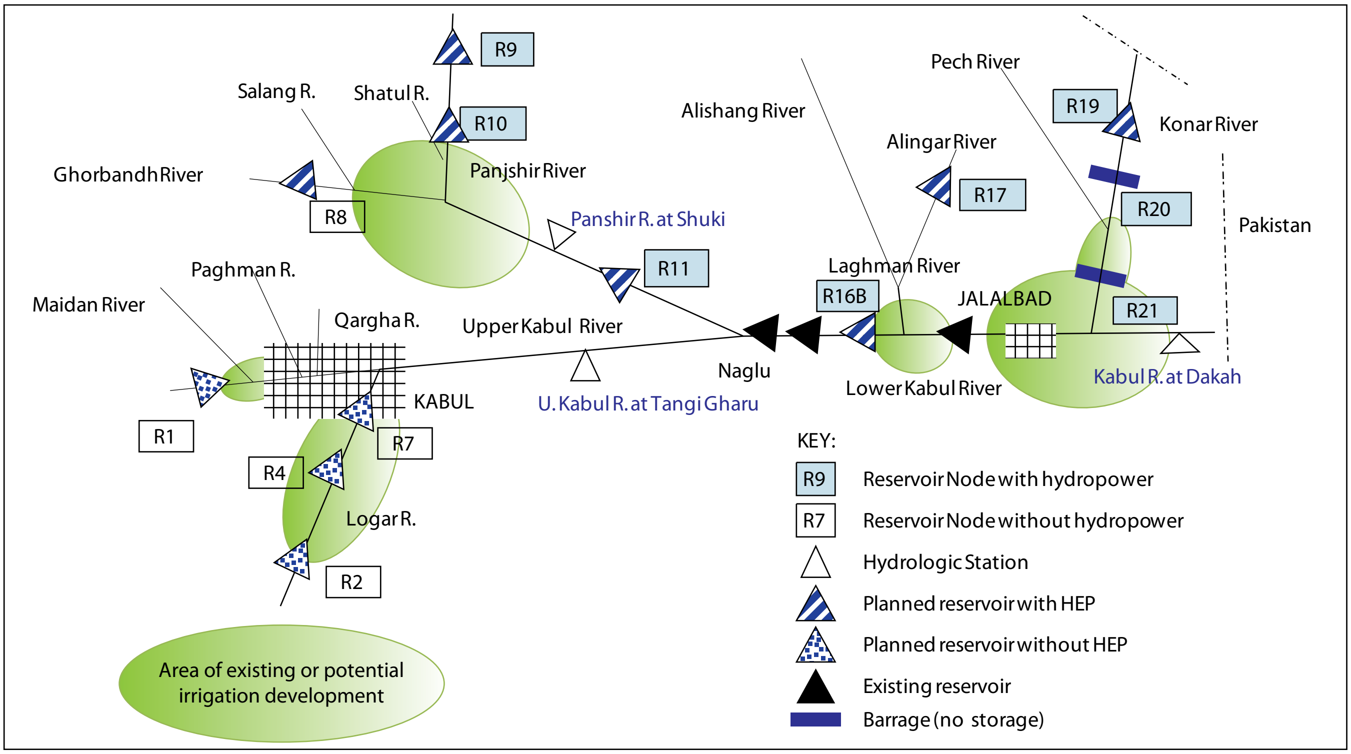
Given the proximity of markets and the agroprocessing industry in Kabul, high-value commercial agriculture in most of this area is possible if improved and more reliable irrigation water supply is provided. The initial assumed cropping pattern is similar to that assumed for the Panjshir

[17] The basin model is concerned with the allocation of water for full development of an area or demand node. Each of these areas will need to be studied in detail to design corresponding development projects.

[18] Prevailing yields and irrigated yield improvement ratios adopted in the Kabul River basin development plan have been used (Montreal Engineering Company 1978, Vol. II, annex E).

[19] The crop coefficients reported in the Upper Kabul River basin plan (Montreal Engineering Company 1978, which are generally consistent with Toosab and RCUWM 2006) have been used with representative evaporation and precipitation data to determine monthly water use for each crop in the actual cropping pattern determined by the model. Effective precipitation is assumed to be 25 percent of recorded precipitation. An overall irrigation efficiency of 40 percent was assumed above, but efficiency is a variable input parameter that is a part of the process of defining each scenario.

**Figure 4.3:** Existing and Potential Areas of Irrigation Development




watershed, with increased area given to wheat, vegetables, and cotton.

The area east of Kabul (D30 in table 4.4) would be irrigated with treated wastewater from the city as sewer coverage and treatment capacity increase. This area cannot be served from any of the surface water sources in this subbasin. Groundwater quality in this area is poor because of salinity in the eastern portion of the Lower Kabul River aquifer.

## Urban and Industrial Water Supply Options

As a first priority, the government has chosen to upgrade and improve the performance and production of the existing aquifers and well fields serving Kabul, and to raise their production capacity up to the estimated yield limits (table 4.6). The three existing aquifers are located in the Kabul valley close to the city. Their characteristics are briefly discussed below:

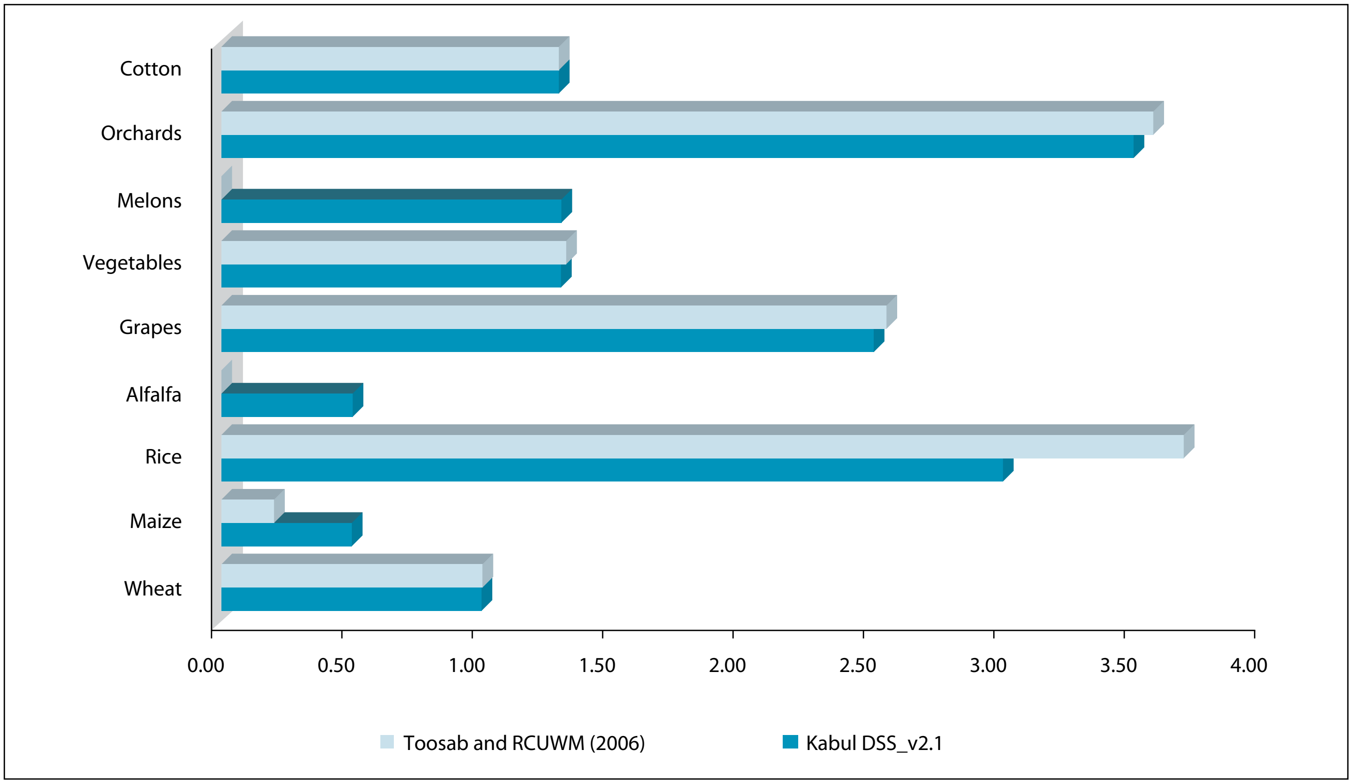
- **Logar River valley aquifer (A1).** The production capacity of this aquifer under the Short-Term Program will more than double to 24.6 million cubic meters per year. The primary source of recharge for this aquifer is streamflow in the Logar River. Its future sustained performance and production depends on ensuring adequate streamflow in the lower Logar River during dry periods.

- **Upper Kabul River aquifer (A2).** The production capacity of this aquifer will be increased from 3.15 to 12.5 million cubic meters per $Mm^3$/yr. This aquifer also depends primarily on recharge from streamflow in the Upper Kabul River.

- **Paghman and Qargha Aquifers (A4 and A4a).** The yield of these aquifers is limited and cannot be increased. Improvements in the well field will enable production to be maintained at 3.7 $Mm^3$/yr.

The fourth aquifer serving Kabul has been referred to as the Lower Kabul River aquifer although it is located largely within the city of Kabul. This aquifer is presently used by private wells and other users. No additional public investment will be undertaken to obtain water from this aquifer for the public network. Table 4.6 summarizes the current and future production capacity of each aquifer, and estimated production and conveyance costs of these

**Figure 4.4:** Crop Net Value Added Relative to Wheat




| Table 4.6 Cost of Production and Conveyance from the Existing Kabul Aquifers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Aquifer** | | **Capacity (estimated sustainable yield)** | **Mode** | **Investment cost** | | | **Annual cost** | **Annual cost per m³** |
| | | **Mm³/yr** | | **M€** | **Including cont.** | **MUS$** | **MUS$** | **US$/m³** |
| **A1** | **Logar I** | 24.6 | Production | €5.03 | €6.04 | $7.25 | $0.85 | $0.03 |
| | | | Conveyance | €19.70 | €23.63 | $28.36 | $3.33 | $0.14 |
| **A2** | **Upper Kabul River aquifer (Allaudin)** | 12.5 | Production | €3.88 | €4.66 | $5.59 | $0.66 | $0.05 |
| | | | Conveyance | €9.01 | €10.81 | $12.98 | $1.52 | $0.12 |
| **A4 & A4A** | **Paghman & Qargha (Afshar)** | 3.7 | Production | €0.09 | €0.10 | $0.12 | $0.01 | $0.004 |
| | | | Conveyance | €2.55 | €3.06 | $3.67 | $0.43 | $0.116 |

*Source: Beller Consult, Kocks, and Stadtwerk Ettlingen 2004.*

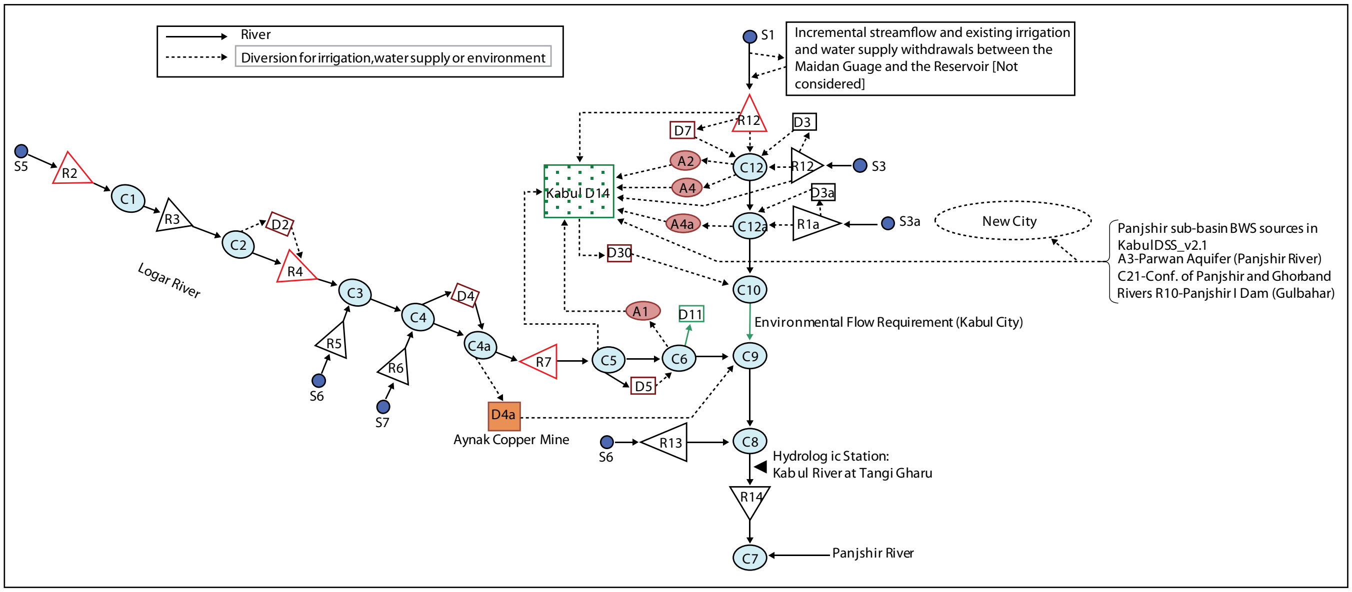
sources based on Kabul water supply feasibility study data.

## Kabul Water Supply Options

Broadly speaking there are three options that Kabul can exercise for a secure source of water supply: (a) tap the Panjshir watershed in the north, (b) develop new sources of water supply within the Upper Kabul watershed where its existing sources are found, and (c) utilize a combination of sources in these two watersheds. Existing sources (table 4.6) and the Panjshir watershed sources are shown in the schematic diagram in figure 4.5. The details of other demands for water in the Logar-Upper Kabul watershed including irrigation and environment are also shown in figure 4.5.[20] The water management and water allocation

[20] Existing and future hydropower development and irrigation development along the main stem of the Lower Kabul River also place demands on the streamflow in the upper watersheds.

**Figure 4.5:** Schematic Diagram of the Logar-Upper Kabul River Sub-basin in Kabul DSS_v2.1




complexity created by these multiple demands is evident. Determining the optimal manner in which Kabul water demand can be met requires and integrated analysis of all sector demands and water resources development options in both the Logar-Upper Kabul and Panjshir subasins.

**Groundwater within the Kabul River basin.** In 2010, the traditional and nearby groundwater sources, that is, the shallow aquifers near Kabul in the Upper Kabul and Logar River valleys (table 4.6), will be at full production capacity.[21] There is some speculation that a deep aquifer exists within the intermontane basin in which Kabul is located. There are current proposals to undertake exploration and investigation of this aquifer to identify and assess this possible resource. While its cost competitiveness will have to be determined through exploration and investigation, it is even more important to identify the source of recharge of this aquifer and estimate its magnitude. It is possible that this could be fossil water, and its extraction to serve Kabul would be a short-term option to fill the gap until equivalent and sustainable production capacity is found to augment and eventually replace this source.

**Additional water resources in the Upper Kabul watershed.** Apart from a possible deep aquifer within the Kabul valley, there are two broad options within the Upper Kabul watershed. First, the Logar River subbasin has substantial flow, and there are a number of storage sites that may be cost-effective in providing sufficient flow regulation to ensure a reliable drinking water supply to Kabul as well as satisfying other demands for water in the Logar basin (for example irrigation, rural water supply, and mining). Storage is likely to be necessary as the 2015 incremental supply requirement is about 25 percent of the mean annual flow of the Logar River, and greater than the mean monthly flow in the months of June through September. By 2020 the incremental supply requirement would be about 32 percent of the mean annual flow. Surface water supply in the Upper Kabul watershed is likely to be problematic because of the concentration of settlements and irrigated agriculture along the narrow river valleys, so treatment of this source is likely to be required.

The Kabul water supply feasibility consultants studied the Gat reservoir located on the lower Logar River close to Kabul. They found that it could close the gap in 2015 as well as serving the irrigation and environmental flow needs below the dam site. There are at least two good reservoir sites upstream of Gat (Kajab and Tangi Wardag) that could also be considered with or without Gat. There is also substantial irrigation in the Logar River valley and the upstream reservoirs could (a) serve the irrigated area upstream and downstream of Gat, (b) provide flow regulation to improve recharge of the Logar River aquifers,

[21] The production capacity of the Logar River aquifer, which has a very large storage capacity, may be somewhat higher than the limit set in the Kabul water supply feasibility study, but this appears to depend on increasing the dependable flow of the Logar River in dry years (infiltration from the river is the primary if not the only significant source of recharge to this aquifer).

(c) supply Kabul directly with surface water, and (d) satisfy environmental flow requirements in the Kole Hashmat Khan Waterfowl Sanctuary and in the Kabul River below the city.

The second option is to increase the development of the resources of the three small rivers that form the Upper Kabul River above the city (see figure 2.3). These rivers recharge the Paghman and Upper Kabul aquifers at present and serve a substantial area of irrigation (see table 2.6). There is at least one attractive storage site at Haijan on the Maidan River that could provide flow regulation, increase recharge, increase intensive irrigation, and provide for the environmental flow requirements of the Kabul River within the city.

**Additional water resources from the Panjshir watershed.** The very large demand for drinking water by Kabul in the future creates a potentially strong linkage between these two watersheds.[22] As noted in chapter 2, the water resources of the Panjshir watershed are much greater than those of the Upper Kabul watershed (see table 2.1). While the Panjshir watershed has substantially more water than the Upper Kabul watershed (see table 2.1), it is approximately 80–100 kilometers away from Kabul, depending on the location of the source, and at least 300–400 meters below the elevation of Kabul, thereby requiring a substantial lift to transport water to Kabul. The 2020 incremental supply requirement is only about 3 percent of the mean annual flow of the Panjshir River at Shukhi (see figure 2.3). The Panjshir watershed can **provide reliable water supply for Kabul and meet substantial irrigation and hydropower generation demands in the watershed.**

Two sources of water for Kabul have been identified in this watershed in the past. The first is surface water from the Panjshir River, either directly from the river at some convenient point below Gulbahar but above the confluence with the Ghorband River, or directly from a reservoir built on the Panjshir River upstream of Gulbahar. The second source is a shallow groundwater aquifer with large area beneath the plain, south of the confluence of the Ghorband and Panjshir rivers. This aquifer has not been explored or investigated in detail, but preliminary hydrogeological surveys in the 1970s speculated on its extent and magnitude. The Kabul feasibility study (Beller Consult, Kocks, and Stadtwerk Ettlingen. 2004) estimated the capacity of this aquifer to be about 153 $Mm^3$ per year (in the basin model it is referred to as groundwater source A3).

As mentioned earlier, water will have to be lifted (300–400 meters over a distance of 80–100 kilometers) from the Panjshir watershed to reach Kabul. Direct diversion from the Panjshir River would also have to be lifted, perhaps more than the groundwater, depending on topographic details. The so-called high-level Panjshir source, in which water is taken directly from the reservoir on the Panjshir, would utilize gravity for part of the distance, but it would involve constructing a tunnel.

[22] They are linked in other ways that have implications for water resources development in each individual watershed, for example by the production and transport of agricultural products, and by the transmission of hydroelectric power.

5

# Analytical Approach

## Introduction

The options presented in chapter 4 represent potentially viable projects. Many are being actively sponsored by sector authorities to achieve the sector development objectives outlined in chapter 3. Most options have been proposed for investment since the 1970s, and many are included in the proposed water sector portfolio of the recent Afghan National Development Strategy (2008). The degree to which each of these options has been studied varies considerably,[23] but typically they have been identified and planned in isolation from options considered or proposed by other sectors.[24] All attempt to develop and use a common hydrological resource and hence are not independent. Many are alternatives to meet the same purpose whose requirem ents will change over time. It is likely that only a few of these options are needed in the middle and long term. Hence, taken together, they do not constitute a rational, sustainable, or efficient investment plan. Indeed, developed separately by individual sectors, they may result is serious water conflicts, foregone benefits, and increased costs.

At first glance, the Kabul River appears to have more than ample water resources to meet future development needs in the basin (see table 3.1). However, as noted in chapter 2 (see figure 2.9 and table 2.1) and discussed in chapter 3, only approximately 27 percent of the substantial flow of the Kabul River at Dakah, where it crosses into Pakistan, originates in the basin upstream of the Konar River (see figure 4.3).[25] It is the upper part of the Kabul River basin, upstream of the Konar River subbasin that will cater to a large part of future water demands, including Kabul's needs. The Lower Kabul River basin, on the other hand, has large existing and planned hydroelectric power capacity, which, if developed, will place a demand on upstream water resources. This will require a shift of streamflow from the spring and summer months to the peak demand winter months. Hence, balancing the overall (annual and monthly) demand for and supply of water in the basin, and allocating water in each subbasin according to space and time, is an important economic planning issue.

While the international dimensions of water resources development in the Kabul River basin are not a subject of this analytical exercise, recognition of these dimensions is critical because development of medium- to long-term water resources investments in the basin would not be possible without agreements with the downstream riparian country.

The larger investment planning question is: Which *combination of options* would *best* meet the projected demands for water in each of the different sectors (agriculture, energy, urban and rural water supply, mining,

23 With the exception of the Baghdara hydroelectric project, whose prefeasibility study was recently completed, and a few studies for which prefeasibility or feasibility studies are under way (for example the dam and reservoir named Panjshir I in chapter 4, and a new site, named Shatoot, which replaces the site named Haijan in chapter 4), most of these options were studied in the 1970s and early 1980s at least at the reconnaissance, prefeasibility, and feasibility levels. There are considerable technical and economic data available concerning most of these options though the cost data, in particular, are out of date.

24 In the late 1970s, a basin plan was prepared for the Kabul River basin in which many of these options were identified and a simulation model used to analyze viable combinations (Montreal Engineering Company 1978).

25 Nearly two thirds of that flow (62 percent) is located in the Panjshir subbasin.

and environment) in a sustainable manner in the future? The combination of options should be in balance with the water resources available in the basin, provide sufficient reliability of services (irrigation, hydropower, and urban water supply), be commensurate with the government's resources to operate and maintain infrastructure, and not foreclose future options.[26] For example, not all 13 dams identified in chapter 4 are needed, nor is it likely that there will be enough water to fill and operate all of them. The question therefore is: Which combination of a limited number of these dams best meets the specific needs and in what sequence should they be developed?

The complex challenges of analyzing and planning the development and management of water supply and demand in the Kabul River basin is evident from the schematic diagram in figure 5.1.[27] This is an expanded version of the schematic diagram in figure 4.3 in which the river network, proposed conveyances (links that move water from one location or subbasin to another) and options (dams, groundwater well fields, hydropower generation facilities, developed irrigated areas, etc.) are represented by nodes and links. An analytical framework represented by the DSS has been developed to analyze this system and alternative investment plans. This DSS has two elements:

- A knowledge base that encompasses all available data that describe (a) water demands and uses for agriculture, domestic and industrial purposes, mining, power generation, rural water supply, and the environment; (b) options for development and conveyance of water supply; and (c) the hydrological system.
- A model that enables the determination of the best possible combination of options to satisfy all demands, which is achievable by maximizing the total net economic benefit under a given scenario, with specific assumptions about water demands, constraints, and future conditions.

[26] At some point, the other dimensions of sustainable use of water resources, including financial (for example operation and maintenance) and institutional (for example management and regulation), would need to be considered in greater detail in evaluating alternative investment plans. It is useful before launching feasibility studies and implementation of options to consider these and other aspects of sustainability and to compare alternative investment plans using these criteria.

[27] All figures are presented at the end of the chapter.

# Knowledge Base

The DSS knowledge base has been developed and compiled in a series of MS-Excel spreadsheets linked by an *Interface* shown in figure 5.2. The essential data describing the elements of the system shown in figure 5.1 are outlined below.

## System Definition

System *Schematic*[28] (figure 5.1) represents the essential network and connectivity of the river basin, including its hydrology, existing and proposed water uses, and existing and proposed infrastructure.

*System nodes* define each node in the network. These consist of start nodes (S), where hydrological flows enter the system; aquifer nodes (A), which represent major sources of groundwater; reservoir nodes (R), which include dams and any hydropower facilities; demand nodes (D), for environmental, urban, rural, industrial, mining, and irrigation water demands; and connection nodes (C), which connect the various links in the river and infrastructure network.

*Conveyances* represent the abstraction and conveyance of water from a source of supply to a demand node (for example, from A3 the Parwan aquifer to D14 the demand node for Kabul). Conveyance to irrigation demand nodes are not modeled separately as their costs are included in the aggregate irrigation investment cost.

## Supply

a. *Climate* includes precipitation (millimeters per month) and evapotranspiration (mm/day) at each reservoir and demand node; representative stations are used in each subbasin.

b. *Inflow* is average monthly flow (million cubic meters per month) at each start node derived from an appropriate river gauging station record; in addition, there are other considerations, namely:

[28] The names in *italics* refer to buttons on the *Interface* (figure 5.2) or the *Economics Interface* (figure 5.3).

i. As the conditions under which the system is stressed (that is, when water is in short supply) are very important for the analysis due to frequent droughts in Afghanistan, data on the frequency and magnitude of streamflow for different drought periods are needed and must be derived from the station data (see below for a discussion of how these data are used). The selection of the hydrological scenario to be used is made on the *Interface* from where the *Inflow* database is updated automatically.

ii. Between the start nodes, where streamflows enter the system and major downstream features such as reservoirs, additions to streamflow from the intervening catchment area between these points are determined from the hydrological record and added to the flow at the downstream node. These data are inputs to the *Reservoir* database.

iii. Return flows are specified for each demand node in terms of the percentage of demand and the downstream node that would receive these return flows. These values are set on the *Interface* and are automatically input into the *Nodes* database.

c. *Reservoirs*. The basic data for dams and reservoirs, including associated hydropower generating facilities, are specified in terms of height of the dam; storage (maximum gross storage, dead storage, maximum live storage); installed capacity (if hydropower is to be generated); capital and annual cost at maximum development; cost-live storage curve coefficients; height-storage and area-storage curve coefficients; and percentage capacity remaining in a specified year (to account for progressive siltation, for example).

i. If the dam is a run-of-river hydropower generation facility then the storage is set to zero.

d. *Groundwater*. For each major aquifer, the sustainable yield (million cubic meters per year) and extraction capacity (million cubic meters per month) is specified.

## Demand

a. *Overall Demand* is the sum of urban, rural, and industrial (including mining) water demand at each of the demand nodes (million cubic meters per month) for each modeled year.

i. Environmental flow requirements to maintain a large wetland and waterfowl sanctuary near Kabul based on the wetland area (in hectares) selected on the *Interface* multiplied by the monthly rate of water requirement (cubic meters per hectare) is located in the *Overall Demand* database.

ii. The environmental flow requirement for the minimum monthly flow of the Upper Kabul River through Kabul (cubic meters per second) is input on the *Interface* for each modeled year and the monthly volume required automatically input to the *Overall Demand* database.

b. *Irrigation*. Each existing and potentially irrigated area is represented by a demand node at which the maximum area that could be developed is specified along with the present cropping pattern (crops, percentage of area planted to each crop), crop consumptive use coefficients, crop calendar, and base crop yield.

i. Net return or income per ton of production is input on the *Economics Interface.*

ii. The default crop yields can be adjusted upward or downward on the *Economics Interface.*

c. *Power*. Generation capacity for each hydropower option is specified in the *Reservoir* database (see above; this includes the consideration whether the facility is run-of-river or storage); energy demand is specified as the minimum and maximum annual energy generation requirement from the basin, not from each dam or facility (see table 4.2), and the monthly distribution of that demand (see table 4.3).

## Costs

All costs are annual costs, in appropriate cases computed with an interest rate of 10 percent and an economic life of 50 years.

a. **Dams, reservoirs, and hydropower generation.** Cost curves (million US$ per year vs. live storage) for each dam and reservoir, including associated costs for hydropower generation facilities, are included in the *Reservoir* database.

b. **Conveyances.** The cost per cubic meter for water obtained through a conveyance link consists of three elements: extraction and storage; treatment; and conveyance, including pumping. Unit treatment costs are specified on the *Economics Interface* and unit pumping costs are specified on the *Interface*. Extraction costs, including fixed costs (capital and operation and maintenance, in $ per million cubic meters) and pumping head (in meters) in the case of groundwater are specified for each conveyance link in the *Conveyance* database. Conveyance costs, including fixed costs (capital and operation and maintenance, in $ per million cubic meters) and pumping head (in meters) for each conveyance link are also specified in the *Conveyance* database.

c. **Irrigation.** All investment costs for irrigation development, including diversion, conveyance, and distribution, have been combined and defined as the irrigation investment cost per hectare ($ per hectare).

# Modeling Framework

The quality of the available knowledge base, the status of various options, the institutional framework, and the decisions to be made dictate the structure and complexity of the modeling framework to be used. The modeling framework used in this current version of the DSS is that of economic optimization subject to various technical and resource constraints. For a given scenario or set of assumptions (section 5.4), the model is designed to determine an optimal set of strategic options.

a. **Objective**. In such an optimization, the objective function represents some formulation of welfare. In this case, the objective of the modeling is to maximize the net productivity of water represented by the net economic benefits of water used in some key water-related sectors. For this study, the net benefit is the gross benefit from irrigated agriculture and hydropower generation less the costs of storage (which includes the cost of the dam and generation facilities), irrigation investment, and conveyances, including pumping. The economic benefits of water supply for urban, rural, industrial, and mining activities are not determined; instead these water demands are estimated and set as constraints to be met as a part of the optimal solution. In other regions, these demands could be set as demand curves so that conservation measures could be selected to change water demands as necessary, depending on scarcity. In Kabul, the fixed demands are reasonable given the current extremely low per capita water use levels, which do not give much room to conserve water further for these uses. In the large irrigation use, however, the choice of crops and areas would help change demands, depending on scarcity. It is possible that when more is known about some of the new growing demands, such as mining, they could be modeled more explicitly in the objective with a demand curve or with conservation options. Game theoretic approaches could also be used to explore competition among sectors or regions.

b. **Constraints**. There are several types of constraints:

   i. The first consists of simple continuity constraints applied to each node in the system (figure 5.1), that is the difference between what enters a node less what leaves must be either zero (that is, "what comes in must go out" of a node) or equal to the change in storage if the node is a reservoir.

   ii. Urban, rural, industrial, and mining water demands, and any specified environmental flows, must be met.

   iii. There are technical and physical constraints, such as reservoir sizing and irrigated area available. These constraints can initially be limited in number to allow for a "no holds barred" analysis to facilitate more creative options, gradually tightened to reflect political, financial, and other constraints.

iv. The optimization framework also allows the computation of shadow prices or values that reflect how hard or limiting a constraint is in the search to maximize the objective, for example the value (in terms of a corresponding change in net benefits) of an additional million cubic meters at a location.

The modeling framework is outlined in appendix B, and the model itself is described in detail in appendix C. The key decision variables in this model include

- flow from one node to its connected downstream node in each month;
- flow in each conveyance between the source node and the demand node in each month;
- storage capacity chosen for each reservoir (could be specified or optimized);
- energy generated at each hydropower facility in each month;
- storage in each reservoir at the end of each month;
- storage in groundwater at each aquifer in each month;
- area under each crop at each location in each month.

Implicitly, the model finds the sequence of monthly water allocations in the basin that result in the maximum net benefit and satisfies all the specified constraints. While it is technically possible to simplify the analysis by examining each subbasin individually, it is evident from figure 5.1 that there is strong interdependence between them, and that infrastructure and other developments in one subbasin can directly affect options in the other subbasins, altering the level and pattern of streamflow. The model seeks the optimal set of water allocations in each subbasin, and for the basin as a whole, that result in an overall optimal basin investment plan subject to the constraints.

## Scenarios and Related Assumptions

A scenario is constituted by combining specific assumptions about the river basin, options, water demands, and the economic situation in the year being modeled. The key parameters that collectively define the scenario and set the conditions for optimization are presented below. The values of these parameters are inputs for the model on the *Interface* (figure 5.2), or the *Economics Interface* (figure 5.3), making the definition of each scenario transparent and facilitating the simple change of assumptions to define a new scenario.

a. The modeled years currently are 2005, 2015, 2020. Forecasts and projections used in this study have been made for these three years (additional years could be added by expanding the DSS knowledge base). In general, the year 2020 is used for most analyses given the long lead times for most of the options. An alternative, but computationally more complex, approach could be to explicitly develop an intertemporal optimization framework to assist in sequencing of options.

b. **Hydrological scenario.** The user must choose one of the four hydrological scenarios presently built into the *Interface*. These include the mean or average year (in which long-term average monthly flows are used by the model), or one of the three alternative drought frequencies (5-year, 10-year, and 20-year) in which the flows are given as a percentage of the long-term mean for a drought period of one year. These estimates are based on the drought frequency analysis for representative stations in each of the major subbasins (Toosab and RCUWM 2006).

c. **Infrastructure options:**

   i. On the *Interface*, the user can select which options, including dams and conveyance connections, are to be considered or available in the scenario. Clicking on the box next to the name of the dam or conveyance connection designates whether the option is in or out of the scenario (all are available in the default Base Case scenario).

ii. The characteristics (for example maximum storage capacity and installed capacity) of all dams can be altered by changing the input data in the *Reservoir* database.

iii. On the *Interface*, the user can decide which of three built-in cost scenarios should be used. These can be adjusted or additional scenarios created in the *Reservoir* database.

d. **Environment demands.** The area of the Kole Hashmat Khan Waterfowl Sanctuary is set on the *Interface;* the environmental flow required in the Upper Kabul River through the city of Kabul for each modeled year is set in a table near the bottom of the *Interface.*

e. **Energy.** Three energy sector parameters need to be set: the winter (January) value of energy produced (US cents per kilowatt-hour); energy exports from the Kabul River basin as a percentage of the minimum and maximum annual energy demand from the basin; and the price of pumping energy (US cents per kilowatt-hour). Annual minimum and maximum energy demand in a particular modeled year can be altered by changing the data in the *Power* database (see table 4.2).

f. **Irrigation.** Several important irrigation sector parameters are set on the *Interface*, including irrigation investment cost ($ per hectare); return flow as a percentage of the flow diverted (percent); yield multiplier (set on the *Economics Interface*) by which the default yields (see table 4.5) can be adjusted upward or downward; overall irrigation efficiency (the product of conveyance, distribution network, and on-farm efficiencies) at each demand node in the modeled year; economic return per ton of production for each crop (set on the *Economics Interface*); percentage of irrigated area at each demand node with the current (default) cropping pattern; and minimum and maximum change that the model can make in the current cropping pattern.[29]

g. **Mining.** The water required by the Aynak copper mine, currently at the initial stage of development in the Logar River basin near Kabul, is potentially very large but uncertain at present. Two options are provided on the *Interface*, namely low and high, based on estimates of the rate of growth of production and water requirements. The return flows from the Aynak mine are also set on the *Interface.*[30]

h. **Water Supply.** The *Overall Demand* database (figure 5.2) includes projections of demand for urban, industrial, and rural water supply for each of the default modeled years (see section 3.3). For instance:

i. Overall average urban distribution system losses (as a percentage of water production) in the modeled year are set on the *Interface*.

ii. Key water supply cost factors are set (*Economics Interface*) including the costs of surface water treatment, groundwater treatment, Kabul wastewater effluent treatment, and agricultural reuse of Kabul wastewater effluent treatment, all in $ per cubic meter.

iii. Projected Kabul population and assumed level of water production per capita for the modeled year are set in the *Overall Demand* database.

Occasionally, scenarios will be infeasible, implying that it is not possible to meet all demands or satisfy all the imposed constraints, and that some constraints would need to be relaxed or adjusted. The aspect of establishing and using scenarios is discussed further in chapter 6.

## Outputs and Results

The model (appendices B and C) operates with the input data and information contained in the knowledge base (section 5.2) and the scenario data (section 5.4). The output or results consist of the values of all decision variables in each month in the modeled year, including the flows for each month in all links and nodes. As noted earlier, the decision variables include

[29] The model adjusts the cropping pattern to maximize irrigation benefits. These parameters limit the extent to which crop choice and area can be changed.

[30] This return flow, and the diversion requirement, could vary widely, depending on the production level and type and level of water conservation measures used. Also, while the diversion for Aynak is planned from the Logar River, the return flows are assumed to be in the Upper Kabul River below its confluence with the Logar River.

- economic information (total net benefit, benefit, and cost breakdown);
- flows between all nodes in each month;
- water supply to Kabul and Aynak from various sources in each month;
- reservoirs selected, maximum live storage volume (size), monthly reservoir storage and release characteristics;
- energy generated at each hydropower facility each month;
- irrigated areas, cropping patterns, areas of each crop in each location, irrigation water demand at each location and for each crop;
- groundwater pumping patterns of aquifers;
- shadow prices of water at various nodes: shadow prices or values are a measure of water scarcity, denoting the change in the objective (total net benefits) for an extra unit of water at that location.

The results of a scenario and model run are written into a series of MS-Excel spreadsheets that can be accessed on the *Interface*. The outputs consist of tables, charts, and graphs that can be easily examined and facilitate subsequent analysis. The results are organized and presented in two ways:

a. First, two summaries are presented on the *Interface* (figure 5.2) and the *Economics Interface* (figure 5.3) to enable a quick assessment of the results of a scenario.

    i. On the *Interface*, a summary is presented of total gross benefit, costs, and net benefits, as well as the annual outflow of the Kabul River basin at Dakah in comparison to the annual flow expected under the hydrological scenario chosen.

    ii. On the *Economics Interface* (figure 5.3), a series of summary tables are presented, indicating the characteristics of all storage reservoirs, energy generation at each reservoir, water supply sources for Kabul, and irrigation development in each subbasin. The *Economics Interface* also includes a detailed breakdown of benefits and costs by subbasin, and a summary of the irrigation, storage, and hydropower, and Kabul water supply programs that constitute the investment plan.

b. Second, the detailed results for flows, demands, irrigation, Kabul water supply, reservoirs, agricultural benefits, groundwater pumping, and power are located in tables and charts that are accessed by the corresponding buttons on the *Interface*. A sample of the output for the irrigation sector is shown in figure 5.4 and for the energy sector in figure 5.5.

Since the outputs are organized in MS-Excel spreadsheets, the data can be readily compiled, combined, charted, and graphed to respond to the issues being discussed. Hence, these outputs could be made part of a structured stakeholder process, thereby facilitating a discussion of options to make informed decisions.

The process of utilizing the scenarios, knowledge base, and model is iterative. Analysis of the results of one or more scenarios commonly leads to new questions or hypotheses to be tested. It may even lead to changes in the modeling requirements (for example in data, objectives, constraints, and decisions) or in the kind of model used, namely for optimization, simulation, or stochastic simulation. It is critical that an adequate base of skilled staff exists to fully understand and own the analytical tools and develop them further as required.

**Figure 5.1:** Schematic Diagram of the Kabul River Basin with river Network, Conveyance Options and Development Options

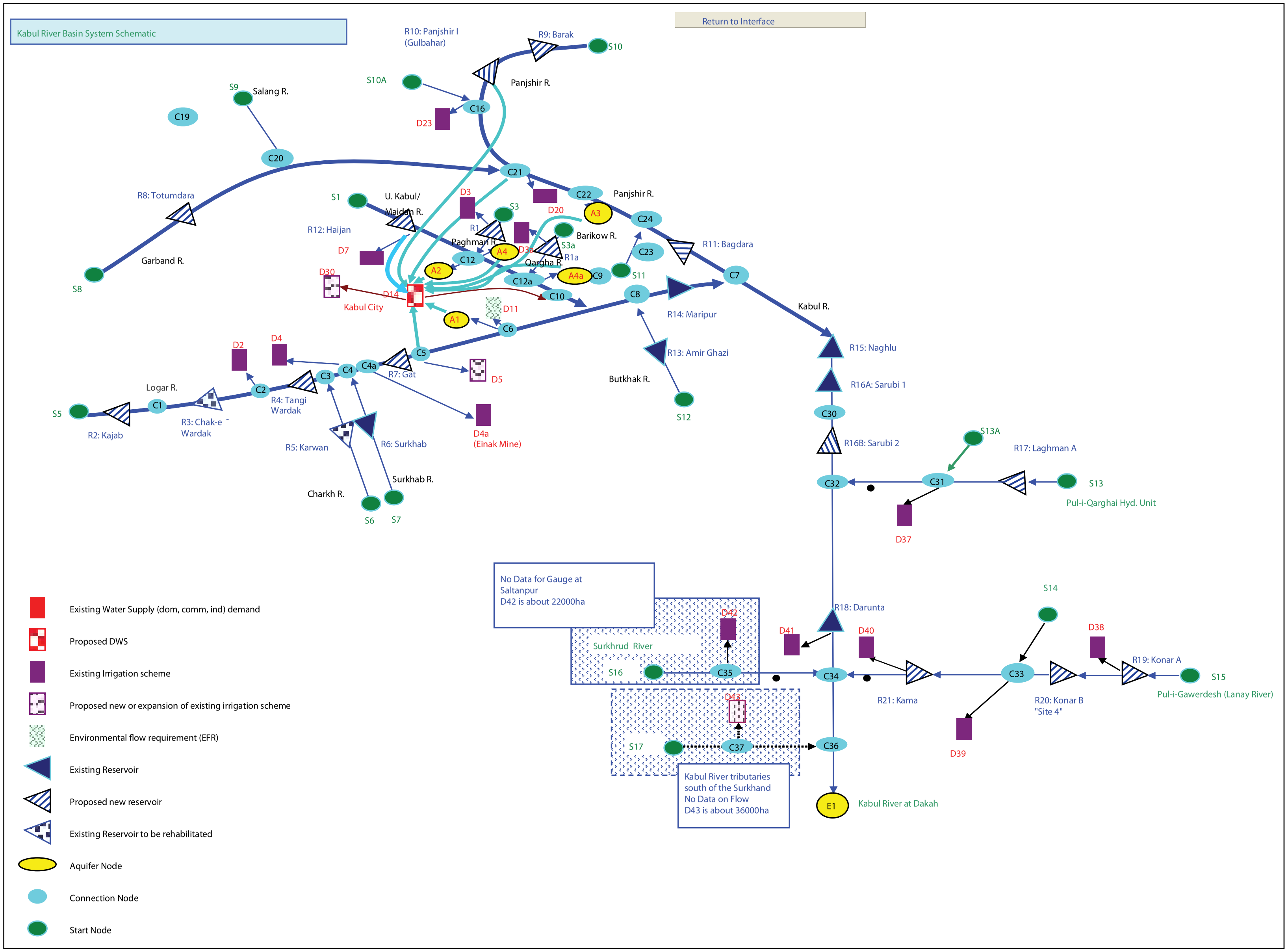
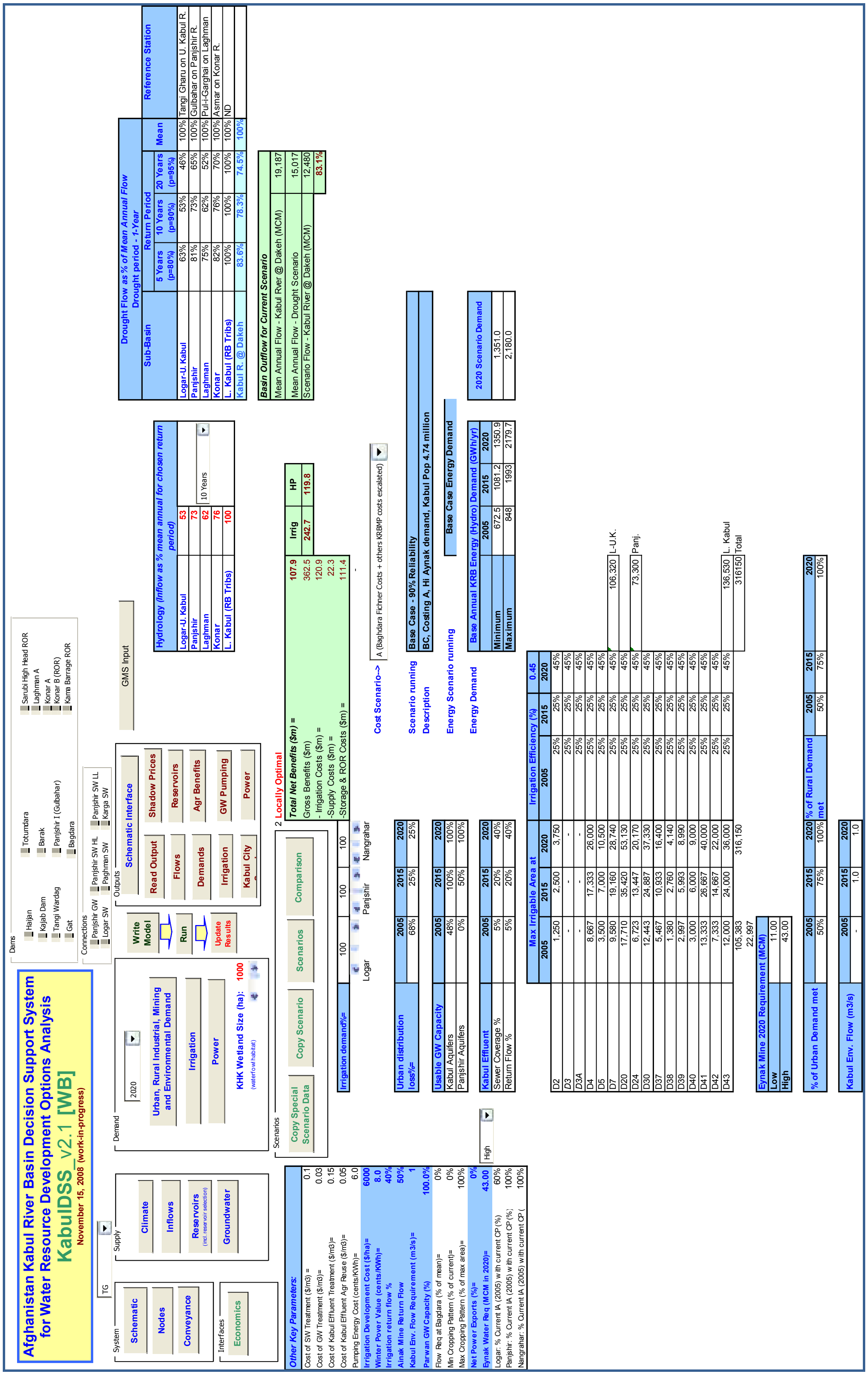


Figure 5.2: Kabul River Basin DSS Interface



## Figure 5.3: Kabul River Basin DSS Economics Interface

### Economics Interface

Return to Interface

2020

| | |
|---|---|
| Cost of SW Treatment ($/m3) = | 0.1 |
| Cost of GW Treatment ($/m3)= | 0.03 |
| Cost of Kabul Effluent Treatment ($/m3)= | 0.15 |
| Cost of Kabul Effluent Agr Reuse ($/m3)= | 0.05 |
| Pumping Energy Cost (cents/KWh)= | 6.0 |

| Crop | Yield Mult. | Net Profit ($/ton) | Dams | Cost Multiplier |
|---|---|---|---|---|
| Wheat | 1 | 50 | | |
| Maize | 1 | 25 | R2: Kajab | 1 |
| Rice | 1 | 150 | R4: Tangi Wardag | 1 |
| Alfalfa | 1 | 25 | R7: Gat | 1 |
| Grapes | 1 | 125 | R8: Totumdara | 1 |
| Vegetbl | 1 | 65 | R9: Barak | 1 |
| Melons | 1 | 65 | R10: Panjshir I (Gulbahar) | 1 |
| Orchards | 1 | 175 | R11: Bagdara | 1 |
| Cotton | 1 | 65 | R12: Haijan | 1 |
| | | | R16B:Sarubi High Head (ROR) | 1 |
| | | | R17: Laghman | 1 |
| | | | R19: Konar A | 1 |
| | | | R20: Konar B (ROR) | 1 |
| | | | R21: Kama (Konar) (ROR) | 1 |

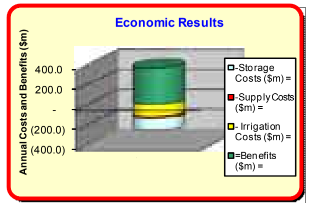
Kajab Dam
Tangi Wardag
Gat
Totumdara
Barak
Panjshir I
Bagdara
Haijan

| | Annual Benefits and Costs ($m) | | | |
|---|---|---|---|---|
| | Total | Logar-Kabul | Panjshir | Nangrahar |
| Irrigation Benefits | 242.7 | 21.98 | 107.18 | 113.57 |
| Hydropower Benefits | 119.9 | 0.13 | 13.88 | 105.89 |
| **Total Benefits** | **362.6** | **22.1** | **121.1** | **219.5** |
| - Irrigation Costs ($m) = | 120.9 | 13.95 | 49.26 | 57.71 |
| -Storage ROR & Costs ($m) = | 111.4 | 10.32 | 39.07 | 62.06 |
| **Total Costs** | **254.6** | **46.51** | **88.33** | **119.76** |
| **Net Benefits** | **108.0** | **(24.40)** | **32.73** | **99.70** |
| -Supply Costs ($m) = | 22.3 | 22.25 | - | - |

| Irrigation Development Program | |
|---|---|
| $1,098 | Investment Cost (M$) |
| 182,930 | Irrigated Area (ha) |
| $666 | NB/ha ($/ha/yr) |
| 22% | IRR (10 yr program) |
| 14% | IRR (15 yr program) |

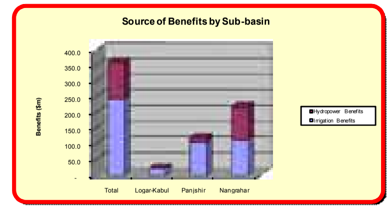
| Storage and Hydropower Program | |
|---|---|
| $1,105 | Investment Cost (M$) |
| $120 | Hydropower Benefits (M$/yr) |
| 2,180 | Energy Generation (GWH/yr) |
| | |
| 853 | Installed Capacity (MW) |
| 6 | No of New Dams & Reservoirs |
| 611 | Live Storage Volume (MCM) |

| Kabul Water Supply Program | |
|---|---|
| 183 | Total Demand (MCM/yr) |
| 151 | Groundwater Sources) (MCM/yr |
| 32 | Surface Water Sources (MCM/yr) |
| 183 | Total Incremental Supply (MCM/yr) |
| $266.0 | Investment Cost (M$) |
| | Share of Storage Investment Cost (M$) |
| $37.9 | Annual Cost (M$/yr) |




| Annual Benefits and Costs | |
|---|---|
| **Total Net Benefits ($m) =** | **107.9** |
| =Benefits ($m) = | 362.5 |
| - Irrigation Costs ($m) = | (120.9) |
| -Supply Costs ($m) = | (22.3) |
| -Storage Costs ($m) = | (111.4) |

| | |
|---|---|
| **Disc Rate=** | **10%** |
| **Life=** | **50** |
| **Escalation** | **2.37** |




| Dams and Reservoirs | Max Storage (MCM) | Capacity (%Max) | Investment Cost (m$) | Annual Cost (m$) | Node | | Cost of Storage $/m$^3$ | |
|---|---|---|---|---|---|---|---|---|
| Kajab | 80 | 29% | $ 64.4 | $ 6.5 | R2 | 1 | 0.082 | R2: Kajab (79.5 MCM) |
| Tangi Wardag | - | 0% | $ - | $ - | R4 | 1 | - | R4: Tangi Wardag (0 MCM) |
| Gat | 5 | 26% | $ 3.4 | $ 0.3 | R7 | 1 | 0.066 | R7: Gat (5.2 MCM) |
| Totumdara | - | 0% | $ - | $ - | R8 | 2 | - | R8: Totumdara (0 MCM) |
| Barak | - | 0% | $ - | $ - | R9 | 2 | - | R9: Barak (0 MCM; 306 GWh) |
| Panjshir I (Gulbahar) | 292 | 36% | $ 387.3 | $ 39.1 | R10 | 2 | 0.134 | R10: Panjshir I (Gulbahar) (289.3 MCM; 48 GWh) |
| Bagdara | - | 0% | $ - | $ - | R11 | 2 | - | R11: Bagdara (0 MCM; 66 GWh) |
| Haijan | 43 | 29% | $ 34.5 | $ 3.5 | R12 | 1 | 0.081 | R12: Haijan (43.2 MCM) |
| Sarubi II (ROR) | | | $ 438.4 | $ 44.2 | R16B | 3 | - | R16B: Sarubi High Head (ROR) (100 GWh) |
| Laghman A | - | 0% | $ - | $ - | R17 | 3 | - | R17: Laghman A (0 MCM;5 GWh) |
| Konar A | 191 | 32% | $ 176.9 | $ 17.8 | R19 | 3 | 0.093 | R19: Konar A (275 MCM; 954 GWh) |
| Konar B (Site 4 run-of-river) | | | $ - | $ - | R20 | 3 | - | R20: Konar B (Site 4 run-of-river) (27 GWh) |
| Kama (Konar River barrage) | | | $ - | $ - | R21 | 3 | - | R21: Kama (Konar River barrage) (42 GWh) |
| | **611** | | **$ 1,104.9** | **$ 111.4** | | | | |
| | | | **$ 1,002.6** | *(Without Logar-U. Kabul Reservoirs)* | | | | |

| Dams and Reservoirs (Energy Production) | Energy Output (GWH) | Dam Height (M) | Capacity (MW) | Average Plant Factor | Potential Capacity (MW) | Node | Avg. Cost $/kwh | |
|---|---|---|---|---|---|---|---|---|
| Chak-e-Wardak | 2 | | 3 | 0.06 | 3 | R3 | | E |
| Barak | - | - | - | - | 100 | R9 | - | |
| Panjshir I (Gulbahar) | 283 | 97 | 100 | 0.33 | 100 | R10 | 0.138 | |
| Bagdara | - | - | - | - | 210 | R11 | - | |
| Maripar | 1 | | 66 | 0.00 | 66 | R14 | | E |
| Naglu | 361 | | 75 | 0.56 | 75 | R15 | | E |
| Sarubi I | 20 | | 22 | 0.11 | 22 | R16A | | E |
| Sarubi II (ROR) | 654 | | 210 | 0.36 | 210 | R16B | 0.068 | |
| Laghman A | - | - | - | - | 33 | R17 | - | |
| Daruta | 23 | | 11 | 0.24 | 11 | R18 | | E |
| Konar A | 836 | 48 | 366 | 0.26 | 366 | R19 | 0.021 | |
| Konar B (Site 4 run-of-river) | - | | - | - | 81 | R20 | - | |
| Kama (Konar River barrage) | - | | - | - | 60 | R21 | - | |
| | **2,180** | | **853** | **0.30** | **1,337** | | **0.051** | |

| Incremental Kabul Water Supply Sources | Node | Annual Supply (MCM) | Annual Pumping Cost (M$/yr) | Annual Treatment Cost (M$/yr) | Annual Fixed Cost (M$/yr) | Investment Cost (M$) | Annual | Total Annual | Avg Cost $/m3 |
|---|---|---|---|---|---|---|---|---|---|
| Existing Sources | | 40 | | | | | | | |
| Parwan Groundwater | A3 | 111 | 10.9 | 3.33 | 19.41 | 225.41 | | | |
| Paghman Dam | R1 | 2 | - | 0.23 | - | 2.28 | | | |
| Haijan Dam | R12 | 13 | - | 1.25 | - | 12.39 | | | |
| Panjshir I Dam | R10 | - | - | - | - | 0.00 | | | |
| d/s of Gat Dam | C5 | 17 | 0.2 | 1.73 | 0.88 | 25.88 | | | |
| Panjshir R. Surface Water | C21 | - | - | - | - | 0.00 | | | |
| *Not including storage costs* | | **183** | **11.0** | **6.5** | **20.3** | **266.0** | 26.83 | 37.87 | 0.265 |

| Irrigation Development by Sub-Basin | | Irr Ben ($m/yr) | Irr Costs ($m/yr) | Irrigated Area (ha) | Max Pot Area (ha) | Water Req. (MCM/yr) | $1,097.58 | Investment Cost (M$) |
|---|---|---|---|---|---|---|---|---|
| Logar-Kabul | 1 | 21.98 | 13.95 | 21,099 | 106,320 | 238 | 665.89 | NB/ha ($/ha/yr) |
| Panjshir | 2 | 107.18 | 49.26 | 74,530 | 73,300 | 1,348 | 22.4% | IRR (10 yrs) |
| Nangrahar | 3 | 113.57 | 57.71 | 87,301 | 136,530 | 1,164 | 13.8% | IRR (15 yrs) |
| | | **242.73** | **120.92** | **182,930** | **316,150** | **2,750** | | |

**Figure 5.4:** Kabul River Basin DSS Irrigation Sector Results

## Irrigation Results

Return to Interface

### Cropping Pattern (ha)

| NODE | WHEAT | MAIZE | RICE | ALFALFA | GRAPES | VEGETBL | MELONS | ORCHARDS | COTTON | Total | Max Net Area | Irrig Intensity % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D2 | 190 | 40 | - | 40 | - | 260 | 40 | 3,110 | 110 | 3,790 | 3,750 | 101% |
| D3 | - | - | - | - | - | - | - | - | - | - | - | |
| D3A | - | - | - | - | - | - | - | - | - | - | - | |
| D4 | 1,300 | 260 | - | 260 | - | 1,820 | 260 | 3,278 | 780 | 7,958 | 26,000 | 31% |
| D5 | 530 | 110 | - | 110 | - | 740 | 110 | 341 | 320 | 2,261 | 10,500 | 22% |
| D7 | 1,440 | 290 | - | 290 | - | 2,010 | 290 | 570 | 860 | 5,750 | 28,740 | 20% |
| D20 | 3,540 | 890 | 1,770 | 890 | 2,660 | 2,660 | 1,770 | 39,840 | - | 54,020 | 53,130 | 102% |
| D24 | 1,340 | 340 | 670 | 340 | 1,010 | 1,010 | 670 | 15,130 | - | 20,510 | 20,170 | 102% |
| D30 | - | - | - | - | - | - | - | 1,340 | - | 1,340 | 37,330 | 4% |
| D37 | 1,910 | 270 | 270 | 270 | - | 1,370 | 7,512 | 4,798 | - | 16,400 | 16,400 | 100% |
| D38 | 480 | 70 | 70 | 70 | - | 350 | 70 | 3,030 | - | 4,140 | 4,140 | 100% |
| D39 | 1,050 | 150 | 150 | 150 | - | 750 | 150 | 6,590 | - | 8,990 | 8,990 | 100% |
| D40 | 1,050 | 150 | 150 | 150 | - | 750 | 150 | 6,600 | - | 9,000 | 9,000 | 100% |
| D41 | 4,670 | 670 | 670 | 670 | - | 3,330 | 670 | 29,320 | - | 40,000 | 40,000 | 100% |
| D42 | - | - | - | - | 755 | - | 1,628 | 793 | - | 3,176 | 22,000 | 14% |
| D43 | - | - | - | - | 2,379 | - | 1,886 | 1,330 | - | 5,595 | 36,000 | 16% |
| Total | 17,500 | 3,240 | 3,750 | 3,240 | 6,804 | 15,050 | 15,206 | 116,070 | 2,070 | 182,930 | 316,150 | 58% |

Net Potential 230,931

79.2%

### Irrigation Water Requirements by Crop (MCM)

| Crop | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WHEAT | 16.4 | - | - | - | 1.8 | - | - | - | - | - | - | 0.6 | 18.8 |
| MAIZE | 13.2 | 14.7 | 11.1 | - | - | - | - | - | - | - | - | - | 39.1 |
| RICE | - | 2.4 | 15.3 | 15.5 | 7.3 | - | - | - | - | - | - | - | 40.5 |
| ALFALFA | - | - | 8.2 | 9.2 | 5.1 | - | - | - | - | - | - | - | 22.4 |
| GRAPES | 21.0 | 22.3 | 23.0 | 11.7 | 1.7 | - | - | - | - | - | - | - | 79.6 |
| VEGETBL | 57.5 | 58.6 | 56.1 | 38.6 | 8.9 | - | - | - | - | - | - | - | 219.7 |
| MELONS | 54.6 | 43.3 | 39.8 | 1.4 | 0.2 | - | - | - | - | - | - | - | 139.3 |
| ORCHARDS | 614.9 | 556.9 | 524.1 | 323.1 | 111.1 | - | - | - | - | - | - | 39.1 | 2,169.1 |
| COTTON | 5.4 | 7.3 | 5.4 | 2.8 | 0.3 | - | - | - | - | - | - | - | 21.2 |
| Total | 783.1 | 705.5 | 683.0 | 402.2 | 136.3 | - | - | - | - | - | - | 39.6 | 2,749.6 |

### Irrigation Water Requirements by Node (MCM)

| Node | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D2 | 16.17 | 13.64 | 10.61 | 7.94 | 3.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 51.69 | 1 |
| D4 | 28.44 | 23.53 | 18.47 | 13.95 | 5.18 | 0 | 0 | 0 | 0 | 0 | 0 | 0.22 | 89.79 | 1 |
| D5 | 7.07 | 5.75 | 4.55 | 3.47 | 1.16 | 0 | 0 | 0 | 0 | 0 | 0 | 0.09 | 22.09 | 1 |
| D7 | 17.48 | 14.15 | 11.22 | 8.57 | 2.78 | 0 | 0 | 0 | 0 | 0 | 0 | 0.24 | 54.44 | 1 |
| D20 | 269.57 | 261.59 | 259.93 | 151.95 | 33.81 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 976.85 | 2 |
| D24 | 102.36 | 99.34 | 98.71 | 57.7 | 12.84 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 370.95 | 2 |
| D30 | 6.13 | 5.21 | 4.04 | 3.01 | 1.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19.69 | 1 |
| D37 | 55.76 | 45.56 | 44.34 | 16.53 | 8.1 | 0 | 0 | 0 | 0 | 0 | 0 | 3.57 | 173.86 | 3 |
| D38 | 16.57 | 14.02 | 13.7 | 8.62 | 4.24 | 0 | 0 | 0 | 0 | 0 | 0 | 2.26 | 59.41 | 3 |
| D39 | 35.98 | 30.43 | 29.74 | 18.71 | 9.2 | 0 | 0 | 0 | 0 | 0 | 0 | 4.91 | 128.97 | 3 |
| D40 | 36.03 | 30.47 | 29.78 | 18.73 | 9.21 | 0 | 0 | 0 | 0 | 0 | 0 | 4.91 | 129.13 | 3 |
| D41 | 160.07 | 135.4 | 132.32 | 83.24 | 40.93 | 0 | 0 | 0 | 0 | 0 | 0 | 21.83 | 573.79 | 3 |
| D42 | 11.68 | 9.57 | 9.16 | 3.05 | 1.36 | 0 | 0 | 0 | 0 | 0 | 0 | 0.59 | 35.41 | 3 |
| D43 | 19.76 | 16.77 | 16.36 | 6.76 | 2.89 | 0 | 0 | 0 | 0 | 0 | 0 | 0.99 | 63.53 | 3 |
| Total | 783.07 | 705.43 | 682.93 | 402.23 | 136.3 | 0 | 0 | 0 | 0 | 0 | 0 | 39.64 | 2749.6 | |

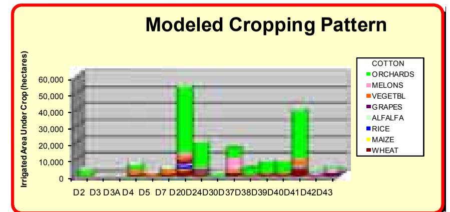
### Net Benefits of Irrigated Agriculture ($m/yr)

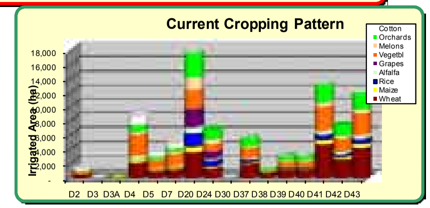
| NODE | TOTAL | WHEAT | MAIZE | RICE | ALFALFA | GRAPES | VEGETBL | MELONS | ORCHARDS | COTTON |
|---|---|---|---|---|---|---|---|---|---|---|
| D2 | 5.81 | 0.02 | 0 | 0 | 0 | 0 | 0.3 | 0.03 | 5.44 | 0.01 |
| D3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D3A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D4 | 8.32 | 0.17 | 0.01 | 0 | 0 | 0 | 2.13 | 0.2 | 5.74 | 0.07 |
| D4A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D5 | 1.65 | 0.07 | 0.01 | 0 | 0 | 0 | 0.87 | 0.09 | 0.6 | 0.03 |
| D7 | 3.86 | 0.19 | 0.01 | 0 | 0 | 0 | 2.35 | 0.23 | 1 | 0.08 |
| D11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D20 | 77.68 | 0.46 | 0.04 | 0.13 | 0 | 2.83 | 3.11 | 1.38 | 69.72 | 0 |
| D24 | 29.5 | 0.17 | 0.02 | 0.05 | 0 | 1.07 | 1.18 | 0.52 | 26.48 | 0 |
| D30 | 2.34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.34 | 0 |
| D37 | 16.14 | 0.25 | 0.01 | 0.02 | 0 | 0 | 1.6 | 5.86 | 8.4 | 0 |
| D38 | 5.84 | 0.06 | 0 | 0.01 | 0 | 0 | 0.41 | 0.05 | 5.3 | 0 |
| D39 | 12.68 | 0.14 | 0.01 | 0.01 | 0 | 0 | 0.88 | 0.12 | 11.53 | 0 |
| D40 | 12.7 | 0.14 | 0.01 | 0.01 | 0 | 0 | 0.88 | 0.12 | 11.55 | 0 |
| D41 | 56.42 | 0.61 | 0.03 | 0.05 | 0 | 0 | 3.9 | 0.52 | 51.31 | 0 |
| D42 | 3.46 | 0 | 0 | 0 | 0 | 0.8 | 0 | 1.27 | 1.39 | 0 |
| D43 | 6.33 | 0 | 0 | 0 | 0 | 2.53 | 0 | 1.47 | 2.33 | 0 |

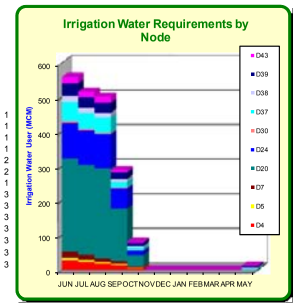
| Location | Cost |
|---|---|
| 1 | 2.51 |
| 1 | - |
| 1 | - |
| 1 | 5.26 |
| 1 | - |
| 1 | 1.49 |
| 1 | 3.80 |
| 1 | - |
| 1 | - |
| 2 | 35.71 |
| 2 | 13.56 |
| 1 | 0.89 |
| 3 | 10.84 |
| 3 | 2.74 |
| 3 | 5.94 |
| 3 | 5.95 |
| 3 | 26.44 |
| 3 | 2.10 |
| 3 | 3.70 |

| Sub-Basin | | Irr Ben ($m/yr) | Irr Costs ($m/yr) | Irrigated Area (ha) | Max Net Area (ha) | Water Req. (MCM/yr) |
|---|---|---|---|---|---|---|
| Logar-Kabul | 1 | 21.98 | 13.95 | 21,099 | 106,320 | 238 |
| Panjshir | 2 | 107.18 | 49.26 | 74,530 | 73,300 | 1,348 |
| Nangrahar | 3 | 113.57 | 57.71 | 87,301 | 136,530 | 1,164 |
| Total | | 242.73 | 120.92 | 182,930 | 316,150 | 2,750 |

| | |
|---|---|
| $1,097.58 | Investment Cost (M$) |
| 665.89 | NB/ha ($/ha/yr) |
| 22% | IRR (10 yrs) |
| 14% | IRR (15 yrs) |



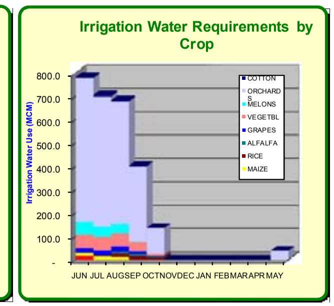
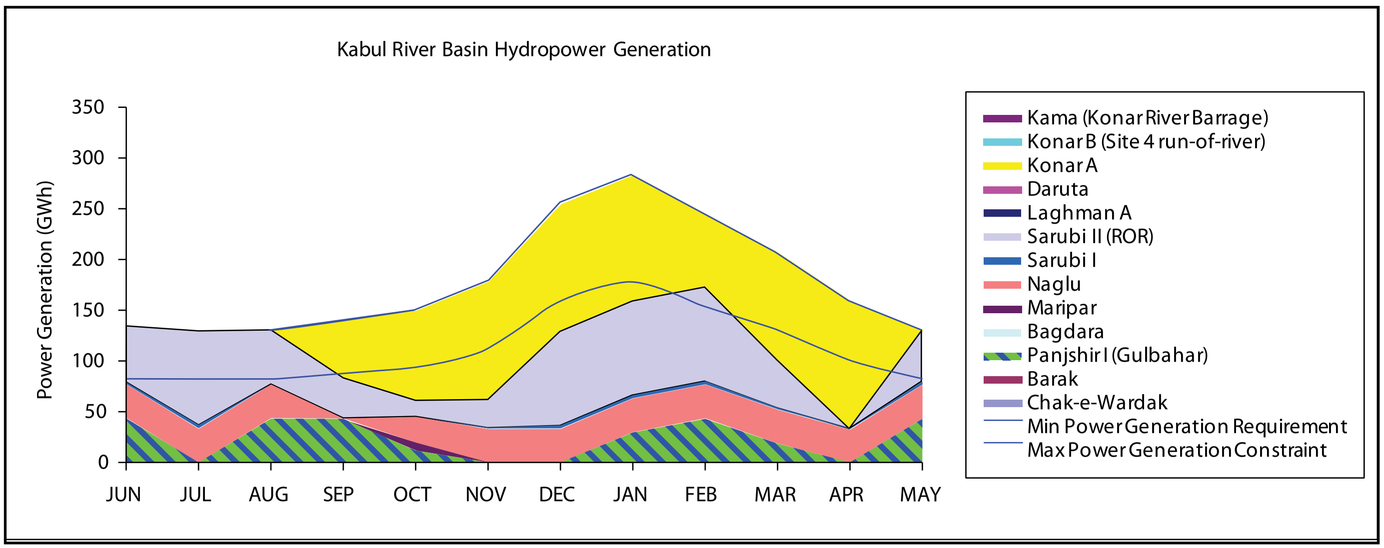



**Figure 5.5:** Kabul River Basin DSS Power Sector Results

| Name | | Energy Production (GWh) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | Total |
| Chak-e-Wardak | R3 | 0.5 | 0.4 | 0.3 | 0.1 | 0.1 | 0 | 0 | 0.1 | 0.1 | 0 | 0 | 0.1 | 1.70 |
| Barak | R9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| Panjshir I (Gulbahar) | R10 | 43.8 | 0.4 | 43.8 | 43.8 | 12.4 | 0.6 | 0.7 | 30.3 | 43.8 | 19.4 | 0 | 43.8 | 282.80 |
| Bagdara | R11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| Maripar | R14 | 0.1 | 0.1 | 0.1 | 0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0 | 1.10 |
| Naglu | R15 | 32.8 | 32.8 | 32.8 | 0 | 32.8 | 32.8 | 32.8 | 32.8 | 32.8 | 32.8 | 32.8 | 32.8 | 360.80 |
| Sarubi I | R16A | 1.8 | 3.4 | 0 | 0 | 0 | 0.9 | 3 | 3 | 3 | 1.6 | 0.6 | 3 | 20.30 |
| Sarubi II (ROR) | R16B | 54.9 | 91.9 | 53 | 39.2 | 15.7 | 27.6 | 91.9 | 91.9 | 91.9 | 46.8 | 0 | 49.3 | 654.10 |
| Laghman A | R17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| Daruta | R18 | 0 | 4.8 | 0 | 0 | 0 | 0.8 | 2.6 | 2.6 | 2.7 | 1.8 | 2.6 | 4.8 | 22.70 |
| Konar A | R19 | 0 | 0 | 3.8 | 60.4 | 91.9 | 118.8 | 126.9 | 125.9 | 74 | 107.8 | 126.5 | 0 | 836.00 |
| Konar B (Site 4 run-of-river) | R20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| Kama (Konar River barrage) | R21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| | | 133.9 | 133.8 | 133.8 | 143.5 | 153 | 181.6 | 258 | 286.7 | 248.5 | 210.3 | 162.6 | 133.8 | 2,179.50 |
| Other Existing | | 2.4 | 8.7 | 0.4 | 0.1 | 0.2 | 1.8 | 5.7 | 5.8 | 6 | 3.5 | 3.3 | 7.9 | 45.8 |
| Total Existing | | | | | | | | | | | | | | 406.60 |

| Sub-Basin | Net Benefits ($m/yr) | Energy Gen (GWH/yr) |
|---|---|---|
| Logar-Kabul | 0.13 | 2.8 |
| Panjshir | 13.88 | 282.8 |
| Nangrahar | 105.89 | 1893.9 |
| Total | 119.90 | 2179.5 |

**Scenario Running...**
**Base Case - 90% Reliability**
**BC, Costing A, Hi Aynak demand, Kabul Pop 4.74 million**



# 6

# Alternative Development Scenarios

## Restatement of Objectives and Development Context

The broad objective of this study is to develop and apply an integrated basin planning framework for evaluating and prioritizing water resources investment options in the Kabul River basin. Over the past five years in Afghanistan, a project-by-project approach in each individual sector has been used and the resulting unprioritized lists of investment proposals, particularly for major water resources infrastructure investments, have attracted little investor interest and have grown in numbers and cost far beyond implementation and financing capacity. The intention of this study has been to show how available data can be assembled in a knowledge base and used in an analytical framework to formulate more rational, strategic investment proposals that address major investment concerns. At the same time, this approach allows an assessment of weaknesses in the available data, and identification of data gaps that need to be addressed as a priority.

The development context that frames this study is the integrated and sustainable development of the water resources of the Kabul River basin for multiple purposes, including domestic and industrial water supply, hydropower, mining and processing, irrigated agriculture, and the environment. The approach involves an analysis of the medium- and long-term options for investment that maximize the economic value (net economic benefit) of water resources development in the basin, that meet the demands for water in all sectors, and that satisfy hydrological and other constraints.

Chapter 3 outlined a possible set of economic, social, environmental, and institutional development objectives and goals (see table 3.4) for water resources development in the Kabul River basin. Table 3.5 summarized a corresponding set of criteria and metrics representing the objectives and goals outlined in table 3.4 by which alternative investment plans would be measured and compared (see also appendix E). The manner in which these criteria are addressed in the analytical approach of this study are discussed below:

a. **Economic.** The specific objective incorporated in the analytical framework is to maximize the total net economic benefit, equal to the sum of the economic benefit of agriculture[31] and power,[32] less the investment cost of storage (and run-of-river options), irrigated agriculture, and Kabul bulk water supply (including extraction, conveyance, and treatment costs). Water allocated to the Aynak copper mine is incorporated in the model as a constraint, that is, a requirement that must be met.[33] Agroprocessing is treated indirectly by allowing the model to choose high-value crops (for example orchards, grapes, and vegetables) that provide inputs to agroprocessing and exports.[34] Employment potential is not considered but the employment effects of alternative

[31] This is calculated as the product of area of each crop (ha) times the yield (t/ha) times the net return per ton of production ($/t) of that crop.

[32] Equal to the monthly energy generated at each hydropower site (GWh) times the monthly value of power (¢ per kilowatt-hour).

[33] The costs of extraction and conveyance from the Logar River are assumed to be incorporated in the development and operational costs of the Aynak mine.

[34] Other crops (for example biofuel production inputs or soybeans) could be added to the agricultural sector part of the model or substituted for one of the crops currently used (see chapter 4) by adding the crop, its monthly water use coefficients, crop calendar, yield, and net return per ton of production.

investment plans could be estimated from model outputs.

b. **Social.** Both urban and rural water supply are treated as social constraints in the model,[35] that is, as water demands to be satisfied; the Aynak copper mine water demand is treated similarly, and other industrial water demand is included in the estimates of Kabul bulk water demand. The model includes an estimate of demand for rural water supply aggregated at each demand node, which is also met in each model run.[36] Poverty and food security are not directly addressed. Direct income impacts are limited to those farm households that own irrigated land, but the broader impacts of an expansion of irrigated agriculture and related economic benefit, including increased on-farm employment and increased purchase of goods and services, would contribute to poverty alleviation through secondary economic impacts in the rural economy. Overall food production and its effects on food security could be assessed from the model outputs. There are no data with which to estimate resettlement caused by the infrastructure recommended in each investment plan. If these data were available, the costs of relocation and compensation would be reflected in the infrastructure cost estimates, the total resettlement impact determined, and constraints applied where resettlement should be avoided or reduced.

c. **Environmental.** Two major environmental issues have so far been identified in the basin, namely minimum streamflow through Kabul and maintenance of the hydrologic regime of the Kole Hashmat Khan Waterfowl Sanctuary, and these are directly addressed by the constraints included in the model. Water quality has not yet been identified as an issue, but reestablishment of the capacity to monitor water quality may point to significant future issues that could create additional environmental flow requirements.

There is extensive traditional irrigation, both intensive and intermittent, varying from year to year depending on water availability, in the Kabul River basin along the river valleys and on the broad plains in the middle Panjshir subbasin and in the Lower Kabul River valley. While Afghanistan has never had a formal, legal system of water rights, customary or traditional rights are well established. Until the breakdown in civil society during the long period of war and civil strife, especially breakdowns in farmers' management of their systems, these were locally enforced through traditional means of water control and conflict resolution. Unfortunately, there are no data that would enable the estimation of these customary and traditional water rights in order to account for them in the DSS and model (which is entirely possible).

In order to examine the development scenarios in the following sections, the analytical framework assesses how best to economically allocate streamflows and groundwater to satisfy water demands for Kabul, the Aynak mine, irrigation development, energy production, and environmental flow requirements. It does not reserve streamflow in accordance with the customary rights of existing traditional irrigation. On the other hand, all irrigated area, whether existing or new potential, is treated in the same manner, that is, as a part of the potential area that could be irrigated. Water is allocated for agriculture at the demand nodes without differentiating between existing and new irrigated areas as they are lumped together as potential.[37] Hence, to the extent that existing irrigated area is included in the area to be developed under a particular scenario, existing water rights are not only preserved but in many cases enhanced.

Nevertheless, in some scenarios and subbasins, a de facto reallocation of water from traditional irrigation to one or more other water uses may occur, especially in scenarios where the development of irrigated area is limited or reduced. This would appear to be a particular problem in the Logar-Upper Kabul subbasin and under some scenarios in the Panjshir subbasin. This is a serious issue that could derail or delay development plans and strategies, unless the development plans include an arrangement to preserve these customary rights or satisfactory agreements with rights holders are negotiated. As with potential resettlement impacts, these social and economic issues need further

35 Water demand for domestic, municipal, and industrial purposes is not price inelastic, that is as water tariffs or private water costs rise demand will decline. Because of the present chaotic state of the Kabul water supply system, it is not possible to estimate a demand curve (i.e. water demand as a function of price) and hence it is not possible to include the economic benefit and cost of Kabul water supply in the objective of the model. In the long term, this will be necessary, especially in light of the very high population and water demands being envisaged. In the shorter term, this should be done for industrial and mining demand.

36 The investment costs for programs to develop these water supplies at the community level are not included, but the allocation of water is made.

37 The analysis in the following sections assumes an average irrigation development cost of $6,000 per hectare. Systems that require modest rehabilitation, including, for example, small water control structures, are likely to cost much less, but upgradation and development of new areas or major headworks and bulk distribution infrastructure are likely to cost much more.

study and quantitative evaluation before an investment plan can be finalized.

## Base Case Scenario

As discussed in chapter 5, each model run is based on the definition of a scenario that consists of the basic assumptions and parameters about the objectives and constraints, mainly the river basin hydrology (drought year, normal year, etc), the configuration and availability of options, water use, and future water and energy demands in the basin. Combinations of development options, objectives, and constraints can be studied by formulating a series of scenarios derived from a basic scenario or Base Case (BC) – this series of scenarios are basically variations on that Base Case. Each model run is based on a unique scenario in the series, and the results from the series of runs are compared.

The model has many default values (chapter 5) that are generally shown on the *Interface* (figure 5.2) and *Economics Interface* (figure 5.3). These remain unchanged unless different values are used to define a scenario. Hence, most scenarios are described as the Base Case with key changes

**Table 6.1 Base Case Scenario**

| **Assumption or parameter** | **Units** | **Value** |
|---|---|---|
| **Year** | | 2020 |
| **Hydrology** (table 3.1) | Percentage of mean annual | 10-year return period drought |
| **Energy** | | |
| Winter (January) value of energy | ¢ per kilowatt-hour | 8 |
| Minimum annual energy generation from basin | GWh | 1,351 |
| Maximum annual energy generation from basin | GWh | 2,180 |
| Energy export from Kabul River basin | % of annual demand | 0 |
| **Agriculture** | | |
| Irrigation investment cost | $/ha | 6,000 |
| Irrigation efficiency | % | 45 |
| Return flow | % | 40 |
| Percentage of potential irrigated area with current cropping pattern | | |
| Logar | % | 60 |
| Panjshir | % | 100 |
| Nangarhar | % | 100 |
| **Kabul** | | |
| Population | Million people | 4.739 |
| Average water production per capita | l/s | 85 |
| Distribution losses (as percentage of production) | % | 25 |
| Pumping cost | ¢ per kilowatt-hour | 6 |
| Surface water treatment cost | $/m$^3$ | 0.10 |
| Groundwater treatment cost | $/m$^3$ | 0.03 |
| **Aynak mine** | | |
| Water demand | MCM per year | High (43.0) |
| Return flow | % | 50 |
| **Environment** | | |
| Kole Hashmat Khan Waterfowl Sanctuary | ha | 1,000 |
| Min flow of Upper Kabul River in Kabul | m$^3$/s | 1 |
| **Infrastructure costs** | | |
| Cost scenario (section 6.5) | | Cost Scenario A |
| **Infrastructure options** | On or Off | All On |

in assumptions and parameters that together define the new scenario. The assumptions and parameters used to define the *Base Case* Scenario are outlined in table 6.1.

## Alternative Scenarios

Appendix E presents a discussion of a large number of scenarios (over 90) that have been analyzed for this study. These discussions are focused on the strategic goals of meeting Kabul's bulk water supply needs, generating electricity from hydropower, and developing irrigated agriculture, as well as satisfying environmental flow requirements. As discussed in chapters 3 and 5, the DSS encompasses the entire basin, and each model run is required to satisfy all demands and constraints everywhere in the basin, regardless of the issue or sector under discussion. Hence in a discussion of Kabul water supply options, for example, the model runs on which this discussion is based not only satisfy the water production requirements for Kabul but also maximize basin energy production and irrigated area and satisfy all other constraints. The groups of scenarios studied include:

a. **Hydrological scenarios.** These are variations on the assumed availability of water in the basin at each of the source nodes (in each of the rivers). Four scenarios have been used, namely the mean annual flow, and three drought conditions namely the annual streamflow available 80 percent, 90 percent, and 95 percent of the time.

b. **Cost scenarios.** There are very limited new cost data available for the infrastructure options, and the most recent data (for the Baghdara hydroelectric project) were used to formulate several cost scenarios in which relative and absolute costs were varied to determine how these affect the choice of options. New data on infrastructure costs are expected from the large number of ongoing feasibility studies that should enable substantial upgrading of the DSS in this regard.

c. **Kabul population scenarios.** The projected population of Kabul on which water production requirements are based was varied from the 2020 projection of 4.74 million (chapter 4) to 8 million. These scenarios incorporate the requirements for a "New City" north of Kabul being considered by the government.

d. **Energy production scenarios.** The Base Case minimum and maximum monthly energy demand (chapter 4) was varied in two ways:

   i. **Energy export requirements.** Both minimum and maximum annual energy demand (and hence monthly energy demand) is increased to simulate cases where the basin is required to generate additional electricity above basin demand to betransmitted to other parts of the grid outside the basin or to export energy to neighboring countries.

   ii. **Mixed hydro-thermal generating system.** The Base Case scenario assumes that all energy demand must be met from the existing and potential hydroelectric generating options in the basin. Because peak irrigation water demand and peak energy demand occur in different times of the year, several alternative energy demand scenarios that are based on a generating system mix of hydro and thermal sources (including imported electricity) were studied. In these scenarios the basin's hydropower sources were assigned primarily to the base portion of the load, reducing the high winter peak demand and smoothing the energy demand over the year.

e. **Irrigation development scenarios.** The model maximizes irrigation development with whatever water is available while meeting all other demands. Storage can be increased to extend the irrigated area and provide for increased summer irrigation demand to the extent that this increases total economic net benefits (that is, the net economic benefits of both irrigation and energy production). In addition, scenarios were formulated to study the effect of lower irrigation efficiency and lower average investment cost per hectare of irrigation development.

## Kabul Bulk Water Supply Scenarios

Table 6.2 shows the optimal options to provide bulk water supply to Kabul under a range of scenarios based on total Kabul population, including the "New City". Each of these five scenarios is based on the Base Case (table 6.1) with the

| Table 6.2 Kabul Bulk Water Supply: Strategic Options with a Conveyance Link to the Panjshir Subbasin | | | | | | |
|---|---|---|---|---|---|---|
| | | Base Case | | | | |
| **Kabul population** | Million | 4.74 | 6 | 6 | 8 | 8 |
| **Parwan groundwater** | Yes/No | Yes | Yes | No | Yes | No |
| **Basin investment plan** | | | | | | |
| Gross annual economic benefits | Million $/yr | 362.5 | 362.5 | 352.8 | 359.1 | 353.8 |
| Investment cost | Million $ | 2,453.4 | 2,548.3 | 2,571.9 | 2,718.7 | 2,824.2 |
| Net annual economic benefits | Million $/yr | 109.5 | 103.6 | 98.0 | 92.1 | 85.3 |
| **Cost of incremental Kabul BWS** | | | | | | |
| Annual cost | Million $/yr | 37.9 | 52.2 | 51.1 | 75.2 | 78.5 |
| Investment cost | Million $ | 266.2 | 364.4 | 443.5 | 561.1 | 675.9 |
| Average unit cost | $/m³ | 0.265 | 0.272 | 0.266 | 0.280 | 0.291 |
| **Incremental Kabul BWS sources** | | | | | | |
| Existing sources | MCM/yr | 39.6 | 39.6 | 39.6 | 39.6 | 39.6 |
| SW: Upper Kabul River | MCM/yr | 14.8 | 14.9 | 14.7 | 14.7 | 14.7 |
| SW: Logar River | MCM/yr | 17.3 | 20.5 | 67.1 | 42.0 | 67.2 |
| SW: Panjshir River | MCM/yr | 0.0 | 1.1 | 110.1 | 55.0 | 187.9 |
| GW: Parwan | MCM/yr | 111.0 | 155.3 | 0.0 | 157.2 | 0.0 |
| **Multipurpose storage** | | | | | | |
| Logar River (Kajab & Gat) | MCM | 84.7 | 80.9 | 61.9 | 61.9 | 66.4 |
| Upper Kabul River (Haijan) | MCM | 43.2 | 43.2 | 43.2 | 43.2 | 43.2 |
| Panjshir River (Panjshir I) | MCM | 292.4 | 292.4 | 292.4 | 292.4 | 292.4 |
| **Cost of multipurpose storage** | | | | | | |
| Logar River (Kajab & Gat) | Million $ | 67.8 | 64.9 | 35.2 | 48.0 | 46.2 |
| Upper Kabul River (Haijan) | Million $ | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 |
| Panjshir River (Panjshir I) | Million $ | 387.3 | 387.3 | 387.3 | 387.3 | 387.3 |
| **Irrigated area: Logar-Upper Kabul** | | | | | | |
| Logar River | ha | 14,009 | 13,652 | 8,090 | 11,120 | 8,090 |
| Upper Kabul River | ha | 5,750 | 5,750 | 5,750 | 5,750 | 5,750 |

*Note: BWS = bulk water supply; SW = surface water; GW = groundwater.*

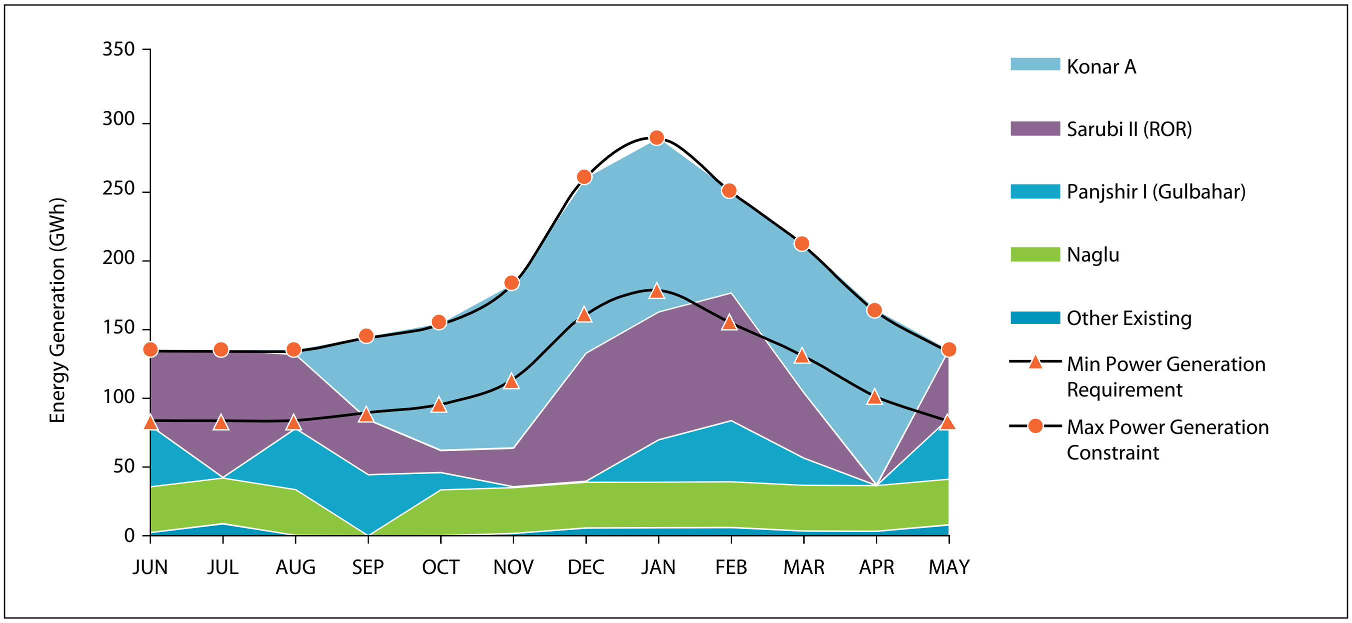
only change being Kabul population and the availability of Parwan groundwater from the Panjshir subbasin. Each scenario assumes that there is a conveyance link between Kabul (and the New City) and Panjshir subbasin. Note that each scenario is optimized individually and the table 6.2 indicates how these results for various scenarios compare with each other.

With a conveyance link to the Panjshir subbasin[38] in place, a requirement to provide bulk water supply to a projected Kabul population up to 8 million at an average water production rate of 85 liters per capita per day (plus assumed losses of 25 percent), along with the full Aynak mine water requirement of 43 million cubic meters, can be satisfied.

From a strategic perspective, looking beyond the original 2020 Kabul population projection of 4.74 million (section 3.3), the scenario in table 6.2, based on a population of 6 million and no Panjshir groundwater, would be an optimal medium-term choice, as it has the lowest unit cost of bulk water supply. This plan is flexible and, if the population increases beyond 6 million to 8 million, the plan can be expanded to meet these increased bulk water supply needs by increasing the allocation of water from the Panjshir River at the

[38] This assumes that multiple surface and groundwater sources are consolidated in a single pumping-conveyance system to bring the water to Kabul as well as meeting other water demands along the transit route such as new urban and industrial areas (e.g., the New City).

**Figure 6.1:** Base Case Energy Generation




Panjshir I dam. This scenario is referred to in the rest of this chapter as the Kabul Medium-Term Plan (KMTP), and further discussed in the following sections and in appendix E.

## Energy Production Scenarios

Five existing hydropower stations in the Kabul River basin are included in the model and they generate between 410 and 448 gigawatt-hours depending on the demand and hydrological scenario. The largest and most important of these is the Naglu dam and reservoir (live storage of 379 million cubic meters and installed capacity of 75 megawatts[39]) located downstream of the confluence of the Panjshir and Upper Kabul rivers.

Figure 6.1 shows the optimal mix of energy-generating options to satisfy basin energy demand with all storage and reservoir options available and the power sector is integrated with all other sectors in the basin. The very great importance of the Konar A storage reservoir is evident in figure 6.1, particularly when the results in figure 6.1 are compared to the results shown figure 6.2 in which the Konar A site is not an option.[40]

In figure 6.2 in which Konar A is not an option, the low or minimum demand can be met all months, but the higher level of demand cannot be met between September and April. In the absence of the Konar A option the Panjshir-Naglu-Sarobi II cascade in the middle and upper Kabul River basin constitutes the core of the basin hydropower generating system, and under a wide range of scenarios, the August to November period is a critical for energy production in this more limited system. This is strongly influenced not only by the choice of bulk water supply options for Kabul and by water demand for agriculture, which is maximum in the months of June through September, but also by the need to provide winter energy.

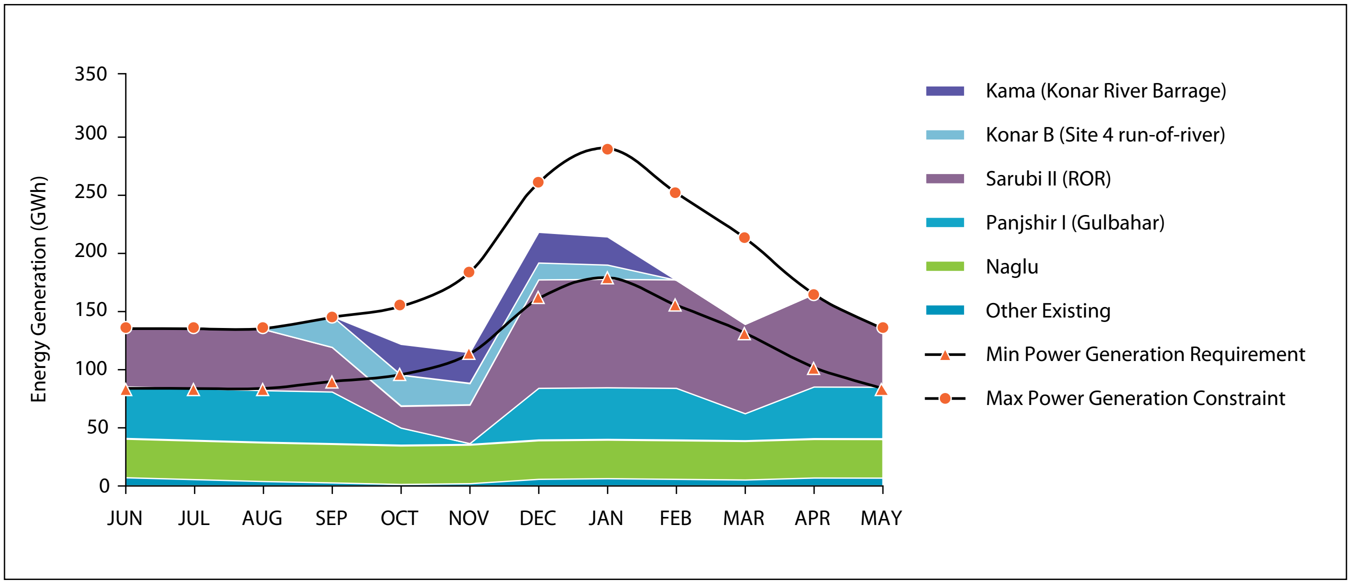
A second important and strategic observation is that the Konar storage project is a critical component of the Kabul River basin hydropower system. When this option is available, total net economic benefits more than double. This option is important for meeting higher levels of demand, especially in the winter peak demand season, and for compensating for shortfalls in generation elsewhere in the system due to low streamflows or increased demand in other sectors. Not only does the Konar A option control the largest and most reliable source of streamflow in the Kabul River basin[41] and

[39] A project to install a fourth 25-megawatt unit is ongoing.

[40] Konar A has the lowest cost of storage in the basin and is the largest and probably most economic source of hydropower, but it is not a likely candidate for early development because of severe security problems and the location of its upper watershed in Pakistan.

[41] Should planning progress on this option? Pakistan's plan to construct a substantial storage and hydropower project, involving a reservoir with live storage of about 715 million cubic meters and 150 megawatts of installed capacity, upstream on the Konar River would need to be considered.

**Figure 6.2:** Base Case Energy Generation (No Konar A; No exports or imports)




comprise the largest volume of live storage[42] and installed generation capacity, it also does not have to satisfy sector demands other than energy. One exception to this in the future might be the requirement to maintain a prescribed level of flow in the Lower Kabul River as it passes into Pakistan.

The hydropower production system for the Kabul River basin, outlined above, can cope with the maximum annual demand curve (section 4.3) enhanced by 30 percent exports as long as the Konar River storage option is a part of the system. However, three considerations suggest that the planning of the Kabul hydropower system, at least for the middle term, should be based on a different and perhaps more realistic demand curve. First, even though there is substantial unmet electricity demand at present in the basin, demand growth will for some time be constrained by the process of upgrading and expanding the transmission and distribution system.[43] Second, hydropower infrastructure has a long gestation period (much longer than for thermal generating sources), and involves detailed planning, feasibility and design, financing, and construction that can extend to 8–12 years or longer depending on the scale, complexity, and site access of the project. Third, it may be important not only from an operating and reliability perspective but also from an economic and financial perspective to broaden the mix of electricity sources to include thermal (from gas and coal) to meet winter peak power and energy demand, to import electricity, and to continue to expand the deployment of other renewables such as solar and wind.

Alternative energy demand scenarios were studied in which imported electricity is assumed to be available in the summer months, and thermal energy is assumed to be used in winter. In the Alternative A demand scenario (table 6.3) 80 percent of the annual energy load is imposed on the hydro system, but only 53 percent of the peak month (January) and 58 percent of the winter period (December–February) energy demand is to be met from the hydro system.

The scenarios shown in table 6.3 are based on the Base Case and the Kabul Medium-Term Plan (table 6.2), and the alternative energy demand scenario described above. Under each of these scenarios, basin irrigation development remains constant but is approximately 6 percent below the maximum, with the decrease confined to the Logar-Upper Kabul subbasin. There is no change in the cost or sources of Kabul water supply.

[42] In the Base Case without power exports, the live storage developed at Konar A is 174 million cubic meters, and in the scenarios with 30 percent power exports it is 261million cubic meters. The latter volume of live storage is the largest utilized under any of the scenarios discussed in this chapter. However, this is just 26 percent of the maximum volume of storage that could be developed at the site. Hence, taking into account the potential future need to regulate the flow of the Kabul River as it crosses into Pakistan, the potential for this option to generate considerably more power and energy, possibly for export to Pakistan as well as elsewhere in Afghanistan, would need to be considered. This also suggests that it may be attractive to design the project to be staged as demand and other commitments increase in the future.

[43] However, since this is at present a high-priority investment of the government, and has attracted substantial donor support and financing, the long gestation period for adding hydropower capacity may still ultimately be the constraint.

| Table 6.3 Alternative Basin Energy Production Systems | | | | | |
|---|---|---|---|---|---|
| **Urban demand** | **Kabul Medium-Term Plan (KMTP)** | | | | |
| **Energy demand** | **Base Case** | | **Alternative A** | | |
| **Electricity supply system** | **Hydropower** | | **Hydro-thermal system** | | |
| **Hydropower options** | **All** | **No Konar** | **All** | **No Konar** | **No Konar & Sarobi II** |
| Basin gross economic benefits (M$/yr) | 352.8 | 326.7 | 372.8 | 372.8 | 346.9 |
| Basin net economic benefits (M$/yr) | 98.0 | 42.2 | 130.5 | 123.6 | 42.6 |
| Basin investment cost ($m) | 2,571.9 | 2,867.3 | 2,448.9 | 2,516.6 | 3,062.7 |
| Basin power benefits (M$/yr) | 119.8 | 93.8 | 139.8 | 139.8 | 111.9 |
| Max. annual energy demand (GWH) | 2,179.7 | 2,179.7 | 1,747.2 | 1,747.2 | 1,747.2 |
| Annual energy generated (GWH) | 2,179.3 | 1,943.3 | 1,747.3 | 1,747.7 | 1,716.4 |
| Energy generated at Panjshir I | 249.6 | 509.3 | 295.9 | 482.1 | 525.6 |
| Energy generated at Baghdara | 0.0 | 0.0 | 0.0 | 0.0 | 281.4 |
| Energy generated at Naglu | 480.0 | 481.8 | 481.8 | 473.9 | 525.6 |
| Energy generated at Sarobi II (ROR) | 685.6 | 723.9 | 634.7 | 733.8 | 0.0 |
| Energy generated at Konar A | 718.7 | 0.0 | 284.4 | 0.0 | 0.0 |
| Energy generated at Konar B (ROR) | 0.0 | 56.8 | 0.0 | 0.0 | 99.6 |
| Energy generated at Kama (ROR) | 0.0 | 115.6 | 0.0 | 0.0 | 218.3 |
| Total storage developed (MCM) | 567.1 | 484.5 | 434.1 | 477.8 | 577.0 |
| Storage at Panjshir I | 292.4 | 411.0 | 292.4 | 404.3 | 418.6 |
| Investment cost of storage (M$) | 1,064.2 | 1,359.4 | 940.9 | 1,008.6 | 1,554.8 |
| Basin irrigated area (ha) | 177,367 | 177,367 | 177,367 | 177,367 | 177,367 |
| Basin net irrigation benefits (M$/yr) | 115.8 | 115.8 | 115.8 | 115.8 | 117.7 |
| Annual cost of Kabul BWS (M$/yr) | 51.1 | 51.1 | 51.1 | 51.1 | 51.1 |
| Investment cost of Kabul BWS (M$) | 443.5 | 443.7 | 443.8 | 443.8 | 443.7 |

Notes: *Base Case Aynak water demand = 43 MCM/yr; Kabul environmental flow requirement =1 $m^3/s$; irrigation investment cost = $6,000/ha; irrigation efficiency = 45%; Naglu = 100 MW.*
*KMTP: Kabul Medium-Term Plan (Population 6 million; no Panjshir groundwater).*
*ROR: run-of-river.*
*BWS: bulk water supply.*

In the Base Case with hydropower alone providing energy to meet basin demand, the run-of-river options on the Konar River provided approximately 9 percent of winter season energy, increasing the total investment cost by approximately 11 percent. These options are not required in the hydro-thermal system (Alternative A) unless the Sarobi II option is dropped, in which case they provide approximately 18 percent of the winter season energy and, with the addition of Baghdara, increase the basin investment cost by approximately 21 percent over the case without the Konar storage option. Hence, the mixed hydro-thermal system and the Alternative A demand scenario appears to be the best choice for a medium-term energy production expansion plan, beginning with Panjshir I and adding Sarobi II as demand rises. The need to construct and commission the more costly Baghdara or the run-of-river options on the Konar River can be avoided if the hydropower cascade is allocated a smaller share of peak winter energy demand.

## Irrigation Development Scenarios

Irrigation development demand in the Kabul River basin is represented by the existing (annual and intermittent) and potential irrigated areas aggregated into 14 demand nodes in the DSS. These demand nodes represent 106,320 hectares in the Logar-Upper Kabul subbasin;[44] 73,300 hectares in the Panjshir subbasin; and 136,530 hectares in the Lower Kabul subbasin (referred to as Nangarhar in the DSS). The purpose is to represent the aggregate water demand from these areas in reasonable relation to the potential sources of water.

[44] The total area of 106,320 hectares includes 37,300 hectares located south and east of Kabul that can only be irrigated with treated wastewater and urban runoff from Kabul. The model assumes the wastewater flows from Kabul are 40 percent of the bulk water supply to Kabul. Urban runoff is not presently included. If the wastewater flows in the months of November to May can be stored, the total area that can be irrigated is about 5,000–6,000 hectares under this assumption and a range of scenarios.

The DSS results indicate target area, cropping pattern, and bulk water allocation with an assumed return flow. These aggregate results need to be translated into specific projects with the necessary headworks, conveyance, and distribution and control facilities. The total investment cost for such a package of irrigation projects at each node is estimated by multiplying the assumed average unit investment cost ($6,000 per hectare) by the target area at that node.

The maximum irrigation development occurs under the Base Case (90 percent reliable water supply), with approximately 183,300 hectares producing direct economic benefit of $123 million per year. The net present value of irrigation benefits is approximately $135 million based on the assumed average unit investment cost of $6,000 per hectare. How this level of basin irrigation development varies under the medium-term plans for Kabul bulk water supply and energy production, and assumptions regarding the availability of surface water for Kabul from the Logar-Upper Kabul subbasin and average irrigation efficiency, is outlined in table 6.4.

In the three scenarios in which there is only hydropower generating capacity, Konar is included as an option. Under these three scenarios, in the case where there is no conveyance of surface water from the Logar River to Kabul and average irrigation efficiency is low, irrigated area declines dramatically in the Panjshir subbasin because of the increased requirement to transfer water to Kabul, high irrigation water demand, and decreased storage at Panjshir I because a larger portion of the energy load is shifted to Konar.

In the hydro-thermal energy demand scenarios in table 6.4 there is no Konar option. In these scenarios the storage at Panjshir I is very high because a significant part of the energy load must be generated at Panjshir I. Still, when the overall average irrigation efficiency is low, there is a significant decline in irrigated area in this subbasin (and in the Logar-Upper Kabul subbasin).

However, not shown in table 6.4 is the effect of reducing the average investment cost of irrigation (see appendix E). If, for example, the average investment cost of irrigation were to be decreased by one third, then the irrigated area in the scenario with hydropower only, no surface water available from the Logar River, and low efficiency would increase by nearly 27 percent.

**Table 6.4 Influence of Strategic Scenario and Irrigation Efficiency on Irrigation Development**

| **Base Case** | | | | | | |
|---|---|---|---|---|---|---|
| **Urban demand** | **Kabul Medium-Term Plan (population = 6 million; no Panjshir groundwater)** | | | | | |
| **Energy production & demand** | **Hydropower only Base Case demand** | | | **Hydro-thermal system Demand Alternative A** | | |
| **Surface water allocated to Kabul from Logar River** | **Yes** | **No** | **No** | **Yes** | **No** | **No** |
| **Irrigation efficiency** | **High** | **High** | **Low** | **High** | **High** | **Low** |
| Basin gross economic benefits (M$/yr) | 352.8 | 363.1 | 289.9 | 372.8 | 383.13 | 354.49 |
| Basin net economic benefits (M$/yr) | 98.0 | 95.8 | 76.8 | 123.6 | 121.6 | 88.8 |
| Basin net irrigation benefits (M$/yr) | 115.8 | 122.2 | 76.5 | 115.8 | 122.2 | 104.5 |
| Investment cost of Kabul BWS (M$) | 443.5 | 543.4 | 563.2 | 443.8 | 543.7 | 564.0 |
| Total annual cost of Kabul BWS (M$/yr) | 51.1 | 63.9 | 66.7 | 51.1 | 63.9 | 66.5 |
| Surface water to Kabul from Logar-Upper Kabul (MCM/yr) | 81.8 | 14.7 | 4.5 | 82.0 | 14.7 | 4.5 |
| Basin irrigated area (ha) | 177,367 | 183,286 | 141,565 | 177,367 | 183,286 | 167,237 |
| Irrigated area: Logar River valley (ha) | 8,090 | 14,009 | 10,158 | 8,090 | 14,009 | 8,090 |
| Irrigated area: Panjshir subbasin (ha) | 74,530 | 74,530 | 38,987 | 74,530 | 74,530 | 66,727 |
| Live storage: Panjshir I | 265.8 | 219.7 | 128.4 | 404.3 | 415.7 | 462.0 |

*Note:* *Base Case Aynak water demand = 43 MCM/yr; Kabul environmental flow requirement = 1 $m^3$/s.*
*Base Case irrigation investment cost = $6,000/ha.*
*Base Case irrigation efficiency = 45%; low efficiency = 35%.*

## Environmental Flow Requirement Scenarios

Two main environmental flow requirements are included in this analysis:

a. Sufficient flow to maintain the Kole Hashmat Khan Waterfowl Sanctuary near Kabul. This flow is defined as the volume of water required to maintain a constant volume of water in the sanctuary (evapotranspiration less precipitation) for a given sanctuary area.

b. Sufficient flow to provide a minimum monthly average flow in the Kabul River as it flows through Kabul.

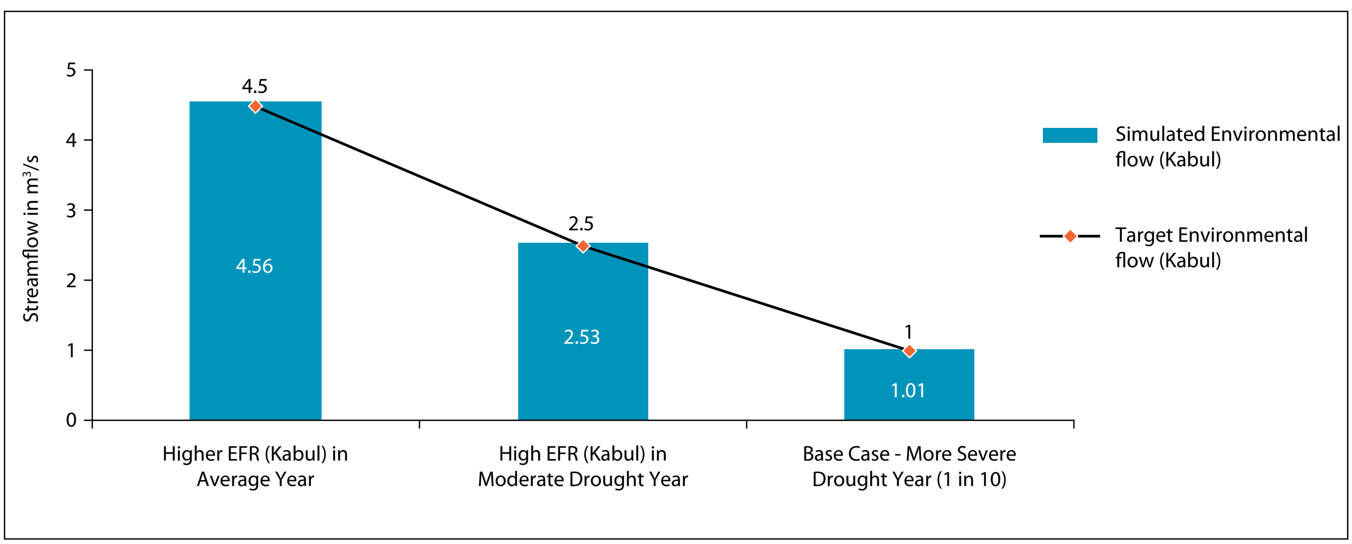
There is little information on the current status of the Kole Hashmat Khan Waterfowl Sanctuary. The area has been neglected, and is subject to encroachment from both urban and agricultural land uses, including encroachment onto the hydrological links with the Logar River. The government has not indicated whether it intends to preserve this cultural and natural landmark. In this study, a relatively large area of 1,000 hectares has been assumed for the sanctuary, and the water requirement to maintain this area is about 0.83 million cubic meters per month or about 0.33 cubic meters per second, with the Logar River as the assumed source.

Three scenarios for the Kabul River environmental flow requirement through Kabul City are compared in figure 6.2 Each scenario is based on the Base Case (table 6.1) but with different streamflow reliability. The reason is that the three target environmental flow requirements (figure 6.24) represent the upper limit for the given flow reliability, that is at 90 percent reliability an environmental flow requirement for the Kabul River greater than 1 cubic meter per second is not feasible. Similarly, for 80 percent reliable streamflows, the maximum feasible target environmental flow requirement is 2.5 cubic meters per second. The actual simulated annual average flow is 2.53 cubic meters per second, and for the higher target of 4.5 cubic meters per second, which is only feasible for the case of mean annual flows, the simulated average flow is 4.56 cubic meters per second.

## An Example of Project Interactions

A key feature of the developed DSS is that it provides a platform where sensitivity to assumptions can be tested quickly. This is useful to better focus on strategic knowledge gaps and examine interactivity across projects and timing of investments. To illustrate this, a real-life example is that of Baghdara and Panjshir storage options (figure 6.3). The Panjshir multipurpose dam (also known as Gulbahar), with benefits to water supply (for example for Kabul City), hydropower, and irrigation (to the large Shomali Plain), is upstream of the proposed Baghdara dam (conceived primarily as a hydropower plant with limited storage). If Baghdara is assessed and designed in isolation,

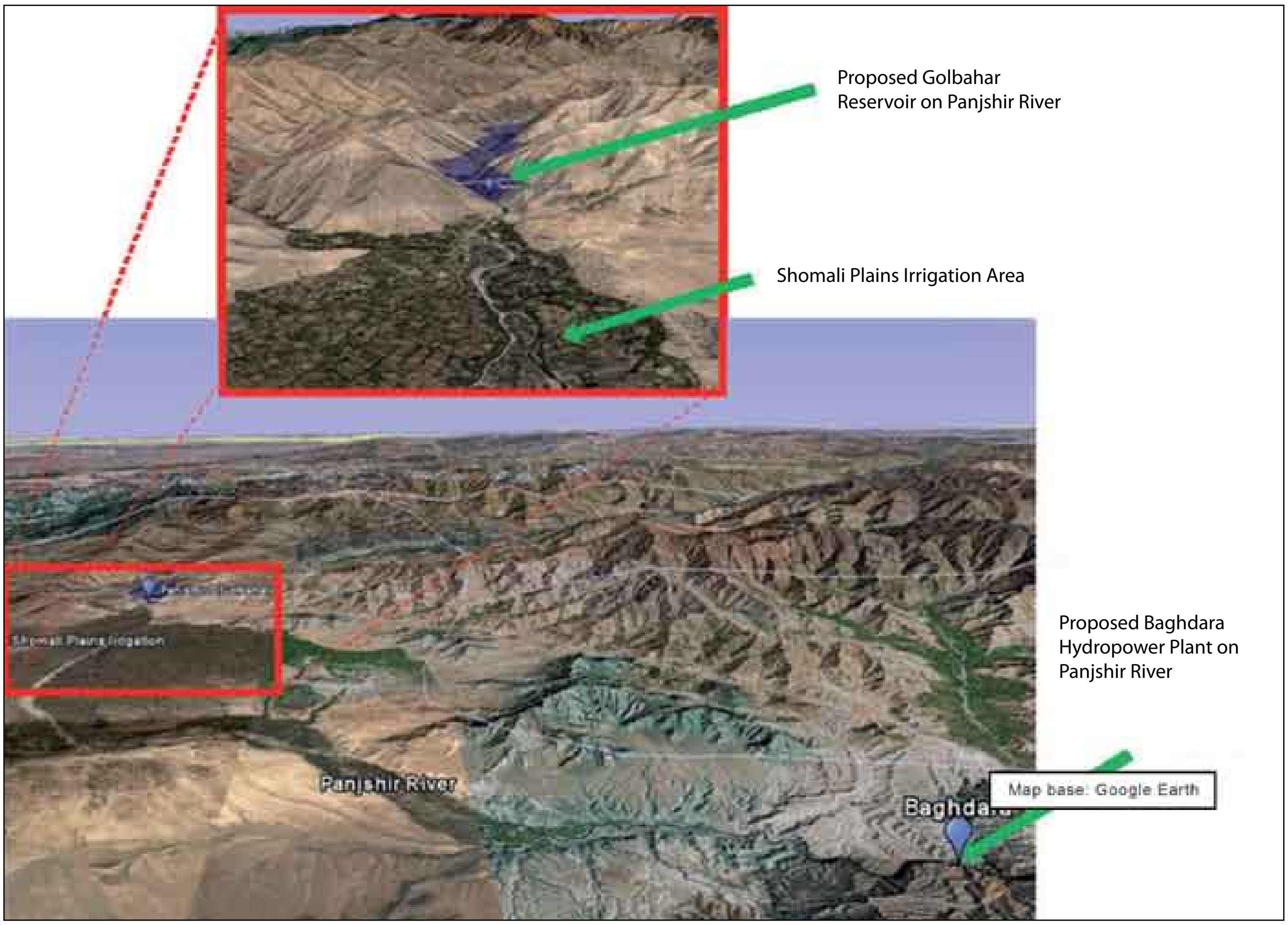
**Figure 6.3:** Feasible Environment Flow Requirements for the Kabul River through Kabul City



it would probably be overdesigned if Panjshir is also built and a substantial quantity of water is consumed as supplemental irrigation to the Shomali Plain. In addition, the hydropower uplift in downstream dams (for example Naglu, Sarobi, and proposed projects such as Sarobi II and Baghdara itself) would also be very different with the storage backing of the multipurpose Panjshir project. The DSS can be used to explore such scenarios with available information to identify knowledge gaps and guide project prioritization.

All this illustrates the point that it is essential to coordinate the timing not only of the projects, but of the preparation studies of the projects. It would be necessary to update initial DSS analysis with any updated costs and basic design information from prefeasibility studies of these projects before deciding on project priorities. This kind of information-based approach will also require (and induce) a very different multisectoral institutional decision-making culture from traditional sector-by-sector and project-by-project approaches.

**Figure 6.4:** Development Options on the Panjshir River



# 7

# Strategic Findings and Way Forward

This study demonstrates the efficacy and value of an analytical basin approach to investment planning in Afghanistan river basins, with attendant emphasis on developing the necessary capacity in the government that would enable it to make informed decisions on water resources investment plans and priorities. Building this capacity, along with the analytical framework, is essential for implementing the decentralized river basin management institutional framework that has been envisaged for Afghanistan and proposed in the draft Water Law. While the challenge of creating such capacity needs to be addressed over the middle to long terms, the urgency of questions that need to be answered for Kabul River basin investment planning has allowed this study to kick-start that process of capacity building.

Despite several key knowledge gaps and uncertainties, studies such as this can rapidly identify strategic findings that enable the government to shift from a narrow sector focus and project-by-project approach to strategic priorities in all sectors. The next section outlines the strategic findings and recommendations of this study. These provide a preliminary set of investment priorities that constitute a water resources development investment plan for the Kabul River basin, and establish priorities for follow-up studies, including the upgrading of the DSS.

## Strategic Findings

The analysis in this study is strategic in that it assesses alternative options and seeks to identify the combination of options that maximizes benefits while meeting the water requirements of various sectors and regions in the Kabul River basin. The results of the analysis set the analytical stage for a multisectoral, multicriterion discussion amongst the stakeholders to decide on goals, targets, and a basin development plan. The plan must create a roadmap for action and investment by various interests, with timelines to achieve the stakeholders' strategic goals. The strategic findings are outlined below, and in all cases the integrated multisectoral approach ensures that the results for a particular sector are consistent with those presented for other sectors.

**Kabul water supply.** The incremental bulk water for a projected Kabul population of 4.74 million can be supplied[45] using surface water from the Logar-Upper Kabul subbasin[46] and surface or groundwater transferred from the Panjshir subbasin. This population level of 4.74 million is only 12–15 percent above the present estimates.[47] If water from the Panjshir subbasin is not available, a Kabul population of only 4 million can be served, at a water production rate of 85 liters per capita per day, and Aynak mine's water supply will also be limited to 10 million cubic meters. Therefore a water conveyance link to the Panjshir subbasin is critical for preventing a constrained bulk

[45] Base Case scenario with streamflow reliability of 90 percent, described in table 6.1.

[46] Full development of Kabul's existing groundwater sources in the Logar-Upper Kabul subbasin would supply about 22 percent of the total water production requirement for Kabul in 2020 at an average per capita production of 85 liters per capita per day.

[47] On completion of the ongoing emergency project to expand and improve Kabul's water supply system, the city is projected to have an average water production rate of about 70 liters per capita per day (see table 3.4) but Kabul's full population would not be served.

water supply situation that will adversely affect urban and industrial development in Kabul.

**Panjshir-Kabul conveyance link.** With a conveyance link to the Panjshir subbasin,[48] a projected Kabul population up to 8 million can be served at a water production rate of 85 liters per capita per day, and full supply of 43 million cubic meters can be provided to the Aynak mine. From a strategic perspective, a scenario[49] based on a Kabul population of 6 million and no Panjshir groundwater would be an optimal *medium-term* choice as it has the lowest unit cost of bulk water supply. This plan is flexible and, if the population increases beyond 6 million to 8 million, it can be expanded to meet these increased bulk water supply needs by increasing the allocation of water from the Panjshir River at the Panjshir I dam.

**Critical storage projects.** This Kabul Medium-Term Plan depends on the development of multipurpose storage in both the Logar-Upper Kabul and Panjshir subbasins. The multipurpose project on the Panjshir River is critically important – it provides 57 percent of the incremental supply, and if the population increases above 6 million, the project will provide an increasing proportion of the bulk water supply needs of Kabul. For a population of 8 million, the Panjshir River would supply 70–95 percent of the bulk water supply for Kabul, depending on how much is supplied from the Logar River. The three multipurpose reservoirs (Kajab, Gat, and Haijan) in the Logar-Upper Kabul subbasin are equally important because without them it is very difficult to satisfy the multiple demands for water for mining, irrigation, rural water supply, and the environment in the subbasin.

**Parwan groundwater.** As the viability of the Parwan aquifer as a potential source of water has not yet been established, the Kabul Medium-Term Plan does not assume its availability. However, if this resource is found to be substantial and the potential negative impacts of abstraction on existing irrigation can be mitigated, then the Parwan aquifer can be substituted for the surface water from the Panjshir River. The absence of Parwan groundwater increases the allocation of surface water from the Logar River from approximately 20 million cubic meters to 67 million cubic meters. If this higher level of surface water from the Logar has to be reduced because of risk, water demand conflicts, or other issues, then the allocation of water from the Panjshir River would have to be increased accordingly.

**Maximum irrigation development.** The maximum irrigation development in the basin is approximately 184,000 hectares[50] under the hydrological assumption of a one-year drought happening once in 10 years. If average annual streamflows are used as a basis for planning, a total of approximately 203,300 hectares could be developed, but the average annual expected shortage would be approximately 19 percent, that is full irrigation water demand would be met up to approximately 80 percent of this area each year. The large difference between the area developed under the average annual streamflow scenario and the once-in-10-years drought scenario occurs entirely in the Logar-Upper Kabul subbasin, as the irrigated area in the other two subbasins is at the maximum potential area. Under all scenarios, the full potential for irrigation development can be accommodated in the Lower Kabul subbasin (87,300 hectares).[51]

**Unit cost and efficiency of irrigation.** Within the overall context of water resources availability in the Kabul River basin, the most dominant variables impacting the development of irrigation are overall irrigation efficiency and the average cost of irrigation development. In the Kabul Medium-Term Plan, irrigated area in the Panjshir subbasin decreases by 48 percent when overall irrigation efficiency is limited to 35 percent. Irrigation development in the Logar valley is sensitive to both the allocation of water from the Logar River to Kabul and to irrigation efficiency. Irrigated area in the Logar valley increases by 73 percent when no water is allocated to Kabul from the Logar River, but then declines from that high level by 27 percent if the overall irrigation efficiency is lowered to 35 percent. Reductions in the overall average investment cost of irrigation development (from the Base Case value of $6,000 per hectare), if feasible, would have a dramatic effect on irrigated area development even if the irrigation efficiencies stay low. With a one third reduction in cost of irrigation development (to $4,000 per hectare), the net irrigated area in the Kabul River basin can almost be

48 This assumes that multiple surface and groundwater sources are consolidated in a single pumping-conveyance system to bring the water to Kabul.

49 Highlighted in table 6.2.

50 This is approximately 2 percent higher under the Base Case with a five-year return period drought (more frequent drought but higher streamflows), but this is the only scenario in chapter 6 under which the area is greater than the Base Case.

51 With the exception of scenarios where irrigation efficiency is low, in which case the irrigated area declines by 2 percent because of the higher water diversion requirements.

maintained at Base Case levels even if overall irrigation efficiency falls from 45 percent to 35 percent.

**Irrigation-urban water supply tradeoff.** Irrigation water diversions in the Logar valley have significant implications for Kabul water supply. When no surface water is allocated to Kabul from the Logar River, the average annual cost of Kabul bulk water supply, including pumping costs, increases by 25 percent, as more water must be conveyed from the Panjshir subbasin.

**Hydropower-only energy production.** If hydropower is the only source of energy generation in the basin, the hydroelectric generation cascade of Panjshir I, Naglu, and Sarobi II is capable of meeting the *minimum* energy demand requirements in all months of the year. Coupled with the two run-of-river options on the Konar River, this cascade can meet the *minimum* demand requirements plus the additional export demand throughout the year. The Konar storage option is required to meet *maximum* demand levels in both cases.

**Mixed hydro-thermal energy production.** Under the assumption that the electricity supply system would consist of a mix of hydro and thermal (coal and gas) generating sources, the Panjshir I, Naglu, and Sarobi II cascade would meet *maximum* demand levels under either Alternative A (the hydropower system is allocated 80 percent of annual energy demand) or Alternative B (the hydropower system is allocated 51 percent of annual energy demand). In the context of the Kabul Medium-Term Plan (Kabul population of 6 million and no Panjshir groundwater), the mixed hydro-thermal system with the Alternative A demand scenario appears to be the best choice of a midterm energy production expansion plan. This would involve investments beginning with Panjshir I, and adding Sarobi II as demand rises. The need to construct and commission Baghdara or the run-of-river options on the Konar River can be avoided if the hydropower cascade is allocated a smaller share of peak winter energy demand.

**Konar storage.** The Konar project is a critical component of the Kabul River basin hydropower system, as it is important for meeting higher levels of demand, especially in the winter peak demand season, and for compensating for shortfalls in generation elsewhere in the system due to low streamflows or increased demand in other sectors. Not only does the Konar A option control the largest and most reliable source of streamflow in the Kabul River basin[52] and comprise the largest volume of live storage[53] and installed generation capacity, it also does not have to satisfy sector demands other than energy. However, developing the Konar option would require reaching an agreement with Pakistan, which may include maintaining a prescribed monthly flow in the Lower Kabul River as it passes into Pakistan.

**Baghdara versus Panjshir.** While the cost estimates currently available suggest that the Baghdara project does not form part of the optimal combination of options in the Kabul River basin, this conclusion is sensitive to the project cost estimates. Therefore, data on resettlement and rehabilitation costs for all projects, and on updated cost estimates for Panjshir I, are critically needed for finalizing the choice of Baghdara or Panjshir I as a priority investment option in the Kabul River basin.

**Kabul River environmental flows.** Under the Kabul Medium-Term Plan, this analysis allows for environmental flows in the Kabul River through the city to vary between 1 and 4.5 cubic meters per second (minimum average monthly flow), depending yearly on the annual flow of the Upper Kabul watershed. No effort has been made yet to determine the minimum needed or acceptable flows in the Kabul River, but the analysis can be quickly updated as and when this information is available.

**Kole Hashmat Khan Waterfowl Sanctuary.** A water allocation can be provided from the Logar River to maintain the Kole Hashmat Khan Waterfowl Sanctuary at a 1,000 hectare expanse, in the Kabul Medium-Term Plan.

The key findings regarding water resources investments options in the Kabul River basin are summarized in box 7.1. Given that it is an international river basin, any significant development of water resources in the Kabul River

52 Should planning progress on this option? Pakistan's plan to construct a substantial storage and hydropower project, involving a reservoir with live storage of about 715 million cubic meters and 150 megawatts of installed capacity, upstream on the Konar River would need to be considered.

53 In the Base Case without power exports, the live storage developed at Konar A is 174 million cubic meters, and in the scenarios with 30 percent power exports it is 261 million cubic meters. The latter volume of live storage is the largest utilized under any of the scenarios discussed in this chapter. However, this is just 26 percent of the maximum volume of storage that could be developed at the site. Hence, taking into account the potential future need to regulate the flow of the Kabul River as it crosses into Pakistan, the potential for this option to generate considerably more power and energy, possibly for export to Pakistan as well as elsewhere in Afghanistan, would need to be considered. This also suggests that it may be attractive to design the project to be staged as demand and other commitments increase in the future.

**BOX 7.1** Key Findings for Water Resources Development in the Kabul River Basin

***Critical conveyance needs.*** A water conveyance link to bring water from the Panjshir subbasin is critical for supplying a Kabul population of more than 4 million. With this link, a Kabul population of up to 8 million can be served, and full supply of 43 million cubic meters can also be provided to the Aynak copper mine.

***Critical storage projects.*** The cheapest (lowest unit cost of bulk water supply) and most flexible option for meeting multisectoral demands in the Kabul River basin requires development of multipurpose storage in both the Panjshir and Logar-Upper Kabul subbasins. The critical storage projects are Panjshir (also called Gulbahar) in the Panjshir subbasin, and Kajab, Gat, and Haijan in the Logar-Upper Kabul subbasin.

***Irrigation.*** The maximum irrigation development in the Kabul River basin is 184,000 hectares, under the assumption of a one-year drought happening once in 10 years.

***Tradeoff between irrigation and urban water supply.*** Irrigation water diversions in the Logar valley have significant implications for Kabul water supply. Irrigated area in the valley increases by 73 percent when no water is allocated to Kabul from the Logar River, but this increases the cost of Kabul bulk water supply by 25 percent.

***Hydropower production.*** With a mixed hydro-thermal system, the Panjshir, Naglu, and Sarobi II cascade can meet the maximum energy demand in the Kabul River basin. A medium-term energy production plan would involve investments beginning with Panjshir and adding Sarobi II as demand rises. In case hydropower is the only source of energy production in the basin, the storage option at Konar is required to meet the maximum demand.

***Konar storage.*** The Konar project is a critical component of the Kabul River basin hydropower system, for meeting higher levels of demand (especially in the peak winter season) and for compensating for generation shortfalls elsewhere in the system.

***Baghdara versus Panjshir projects.*** While the currently available cost estimates suggest that the Baghdara project does not form part of the optimal combination of options, updated cost estimates for the Panjshir project and resettlement and rehabilitation costs for all projects are needed to finalize the choice of Baghdara or Panjshir as the priority investment option in the Kabul River basin.

basin with international support would hinge critically upon reaching a transboundary waters agreement with Pakistan.

## Priority Improvements to the Kabul River Basin Knowledge Base and DSS

While this study has compiled the available data from various sources in order to enable a first-order strategic analysis of the Kabul River basin, the quality of data in the knowledge base on which the DSS rests would need to be improved in order to increase the level of confidence in the findings, especially concerning the identification of priority options. The analysis results are especially sensitive to hydrology, investment costs, net returns to irrigated agriculture, and the scope for expansion of higher-value crops. For example, if updated costs of Panjshir I were to be higher than the Baghdara costs used in this study, this might cause Baghdara to be the preferred storage option, restricting irrigation development in the Panjshir subbasin and greatly increasing the cost of water supply to Kabul.

**Hydrology.** The available hydrological records are of short duration (10–15 years) and old, dating to the 1960s and 1970s. The hydrometeorological data collection networks were subsequently destroyed, but are now being gradually reestablished. The Emergency Irrigation Rehabilitation Project is supporting installation of 174 new stations. Water resources infrastructure projects, especially dams and hydropower stations, tend to have long gestation periods, which can enable improvement in the hydrological records that support project planning and design. The highest priority for new hydrometeorological stations should therefore be given to dam sites in the Logar-Upper Kabul and Panjshir subbasins.

**Kabul water supply options cost estimates.** The optimum combination of water supply sources to satisfy different levels of Kabul water demand depends critically on knowledge of the key cost factors, including extraction at the source, pumping and conveyance, and treatment. In this context, the following studies are needed urgently for a strategic plan for Kabul:

- Detailed hydrogeological exploration and investigation of potential sources of groundwater in Parwan Province, including sources and rates of recharge, sustainable yield, relation to irrigated agriculture in the Shomali Plain and streamflow in the Panjshir River, and costs of extraction and conveyance to Kabul at different levels of development;

- Preliminary engineering studies of alternative surface water sources in the Panjshir subbasin, including headworks and conveyance costs at different levels of development;

- Preliminary engineering studies of treatment modalities and costs at different levels of development for surface water from both the Logar-Upper Kabul and Panjshir subbasins and for groundwater from Parwan Province.

**Prefeasibility studies of storage and run-of-river options.** The relative costs of storage options determine not only which options are the most favorable but also the overall cost of the basin development plan. Finalizing this critical component of the development plan depends on updating and upgrading, to at least prefeasibility level, the key data on these options, including

- updated estimate of costs curves;

- social assessments, including estimates of water allocation, resettlement, and other reservoir impacts for different levels of development;

- updated estimate of installed capacity and related hydropower generation and transmission costs, taking into account ongoing and planned grid expansion;

- updated dam and reservoir characteristics (storage-elevation-area curves).

**Logar-Upper Kabul subbasin planning.** While this analysis has used the currently available data for identifying strategic priorities in the Kabul River basin, preparation of a specific investment plan for the Logar-Upper Kabul subbasin would need a more comprehensive updating of the knowledge base, including

- updated studies of present land and water use;

- updated studies of storage sites and potential and costs, including resettlement;

- upgraded topographic information, mapping and hydrological monitoring;

- data on existing water diversions and estimates of irrigation return flows;

- agroeconomic assessment of existing and potential future agricultural development.

**Data on irrigated agriculture.** The data on agroeconomic systems in the basin are sparse and outdated. Critical knowledge needs pertain to cropping patterns, yields, production costs, prices paid and received by farmers, farmers' water management systems and related infrastructure needs, and identification of appropriate agricultural technologies and practices compatible with climate, soils, and farmers' capacities. In order to translate the analysis results into specific irrigation development plans, the total irrigation potential identified at each node would need to be divided into separate project packages, based on a detailed mapping of the topography, land use, and infrastructure.

**Additional analytical tools.** The analytical framework needs to be expanded to include a basin simulation model that can enable long-term analysis of the operation of the system, determine the reliability of supply, and identify critical flow sequences and other conditions using both the historical hydrological record and a long synthetic record developed from the historical record using statistical methods. Such a model is an essential complement to the economic optimization models such as the one used in this study.

## Strategy for Accelerating Water Resources Development in Afghanistan

In the larger context of national security and stability in Afghanistan, it is critical to increase the scale and accelerate the delivery of water resources projects. The analytical framework and tools developed by this study directly support the process of identifying priority investments in the Kabul River basin, and moving towards their implementation with coordinated international assistance. The strategy for accelerating new water resources development in Afghanistan needs to move in parallel on four fronts:

**In Kabul River basin: Address key data gaps and prepare investment plan.** This study has demonstrated the value of a systematic and multisectoral basin analysis for evaluating various development scenarios and identifying priority water resources investments in the Kabul River basin. As more and improved data are available, a revised basin analysis should be undertaken to strengthen this analytical framework, and use it as the basis for developing and implementing a Kabul River basin water resources development investment plan, with clear and prioritized investments. The different variations of the Kabul Medium-Term Plan outlined in this report could provide an appropriate starting-point.

**In other river basins: Start analysis and planning.** While this study has been focused on the Kabul River basin, systematic and multisectoral analysis should be initiated at the earliest opportunity in other river basins of Afghanistan in order to

- address the lack of clarity on priority options that is resulting in delays and a poor use of resources dedicated to project preparation;
- understand the water resources situation at the national level, including possibly important interbasin linkages and dependencies, such as energy and food grain production;
- assess the combined set of identified priority options in the context of the financing envelope available for the water sector at the national level;
- understand the levels of current and future use of water, which is fundamental to developing Afghanistan's position on international waters dimensions in each of the shared river basins.

As summarized in appendix A, various international development partners have committed to water resources rehabilitation and development in respectively selected basins, in addition to supporting specific policy, planning, and capacity dimensions at the central level. Identifying priority options in each basin and subsequently developing a strategic national list of projects can provide the conceptual underpinnings for moving forward the water infrastructure investments supported by the international development partners in their respectively adopted basins, and help focus the available financial and human resources to achieve optimum results.

**Capacity building as a cross-cutting imperative.** Building the capacities for strategic planning and project preparation is key to answering the critical questions and moving towards implementation. The Afghanistan National Development Strategy recognizes the need to focus strategically on addressing the capacity constraint at the two main levels: integrated water resources management and improving the quality of project preparation. The government has initiated efforts for developing in-house multisectoral water planning capacity by establishing a Water Resources Planning Unit in the Ministry of Energy and Water. However, the government's current capacity is very limited, and efforts need to be started at the earliest on the following fronts:

- Closing data gaps in the hydrological record;
- Improving the quality of preparation studies to investment grade standards;
- Updating project costs dating from the 1970s to the current environment;
- Developing an appropriate set of planning tools for each basin;
- Addressing the constraint of limited staff and skills base.

In addition, the critical gap in international waters capacity in Afghanistan needs to be urgently addressed. The existence of a core multidisciplinary Afghan team is a precondition for building effective international waters capacity, and it is imperative that the government constitute a dedicated and professional team for focusing the international capacity-building assistance that is being made available by the World Bank and other development partners.

**Strengthening institutions for multisectoral water resources decision making.** A start has been made on intersectoral coordination with the establishment of a Supreme Council for Water Affairs Management, which incorporates the ministers of key water-related ministries, namely the Ministry of Energy and Water, the Ministry of Agriculture, Irrigation, and Livestock, the Ministry of Urban Development, and the Ministry of Mining and Industry, in addition to the National Environmental Protection Agency. The Supreme Council for Water Affairs Management is headed by the First Vice-President of Afghanistan, and judged by its design, it is the most progressive institution for intersectoral water resources decision making in Central and South Asia. However, achieving real coordination between different ministries at the decision-making level will be very challenging in practice, and leadership will be required from both the Supreme Council for Water Affairs Management and the Ministry of Energy and Water for

- effectively managing the finalization of the basin development plan for the Kabul River basin and initiating preparation of similar plans for other river basins in Afghanistan, working closely with different sector ministries and other stakeholders;
- coordinating decision making within the government on multipurpose water infrastructure investments, building consensus on and ensuring acceptance of investment plans by different sectoral interests.

## Progress on Next Steps

In 2008, the World Bank was requested by the government to provide technical assistance for building Afghanistan's capacity for strategic basin planning and project preparation. This was proposed to be supported by the multidonor Afghanistan Reconstruction Trust Fund. With fast-track preparation, the Afghanistan Water Resources Development (AWARD) technical assistance project was approved by the Afghanistan Reconstruction Trust Fund Management Committee in December 2008, and became effective in early 2009.

The project aims at (a) capacity building of government of Afghanistan agencies, primarily the Ministry of Energy and Water, for water resources development planning in an integrated basin context; and (b) providing support to the Ministry of Energy and Water for effective preparation of water resources development investments embedded in a strategic basin context. The primary focal units for this technical assistance are the Water Resources Planning Unit and the Project Preparation Unit at the Ministry of Energy and Water.

The technical assistance is provided in a learning-by-doing mode. Accordingly, the Ministry of Energy and Water staff and external expert consultants would work together on the execution of tasks and studies under the scope of the project, with the role of the consultants planned to gradually scale down as Ministry of Energy and Water staff increasingly take on technical responsibilities. The scope of work for the AWARD technical assistance project includes basin planning for selected major basins, whereby strategic basin planning would be conducted in close collaboration with the international development partners active in each basin, for example the European Commission in the Kunduz basin, the U.S. Agency for International Development (USAID) and the Canadian International Development Agency (CIDA) in the Helmand basin, and the Asian Development Bank (ADB) in Balkh and the western basins, to identify priority investments. Project preparation resources would be focused on identified priority investments, supported in the preparation and implementation phases by development partners based on their geographic and sectoral emphases. This umbrella institutional framework being developed and implemented by the government is being endorsed by the development partners in the water sector, so that international support can be coordinated and synergized to accelerate the much-needed water resources development in Afghanistan.

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# Appendix A. Summary of Donor Engagement in the Water Sector in Afghanistan

Table A.1 summarizes the activities of various bilateral and multilateral international development partners active in the water sector in Afghanistan.

**Table A.1 Activities of Water Sector Development Partners in Afghanistan**

| **Organization** | **Water sector activities** |
|---|---|
| Asian Development Bank (ADB) | Support to western basins and Balkh River basin projects; support to natural resources and agricultural sector projects |
| Canadian International Development Agency (CIDA) | Construction of Dahla dam; cofunding of western basins project; contributions to NSP |
| European Commission | Support to Kunduz River Basin Program and Amu Darya (Kokcha-Panj) River Basin Program; support to National Solidarity Program (NSP) and other rural development projects |
| Food and Agriculture Organization of the United Nations (FAO) | Studies, consultancy support and capacity building in agriculture and water resources sectors |
| German Agency for Technical Cooperation (GTZ) | Support on institutional and legislative aspects of water resources development; institutional strengthening of Kabul, Herat, and Kunduz water supply; support on micro-hydropower and renewable energy |
| Government of China | Funding and implementation of Parwan irrigation project |
| Government of Denmark | Contributions to NSP |
| Government of India | Construction of Salma dam; rehabilitation of Amir Ghazi and Qargha dams; capacity building |
| Government of Islamic Republic of Iran | Capacity building; establishment of a research institute at Ministry of Energy and Water |
| Government of Norway | Contributions to NSP |
| Inter-American Development Bank (IDB) | Support to development of western river basins |
| Japan International Cooperation Agency (JICA) | Feasibility studies of different water resources projects; water resources management activities in Balkh basin (through ADB); study of water supply and wastewater for Kabul urban area; preliminary design of water supply and sewerage systems for New City at Dehsabz; contributions to NSP |
| KfW | Financial support to rehabilitation and upgradation of water supply systems in Kabul, Herat and Kunduz; financial support to micro-hydro installations |
| Swedish International Development Cooperation Authority (Sida) | Support to Shamlan canal; educational capacity-building programs |

| Table A.1 Activities of Water Sector Development Partners in Afghanistan | |
|---|---|
| **Organization** | **Water sector activities** |
| U.K. Department for International Development (DFID) | Contributions to NSP |
| U.S. Agency for International Development (USAID) | Support to domestic urban and rural water supply and sanitation; Kajakai hydropower plant; Helmand basin development; capacity development |
| U.S. Geological Survey (USGS) | Support to research on groundwater |
| United Nations Children's Fund (UNICEF) | Support provision of safe drinking water and sanitation facilities; water and sanitation aspects of disaster relief |
| United Nations Educational, Scientific, and Cultural Organization (UNESCO) | Support for a National Water Resources Development Plan; support to National Hydrology Committee of Afghanistan; capacity building |
| World Bank | Support and direct contributions to numerous water sector projects and capacity building (irrigation rehabilitation, urban water supply, rural development); Afghanistan Reconstruction Trust Fund administration |

# Appendix B. Outline of DSS Analytical Framework

## Resources

The key resources utilized for the development and use of the analytical framework were:

- maps/GIS and remote sensing data
- master plans/reports (see references)
- discussions/feedback

## Key Investment Options

The key investment options examined in this DSS for the Upper Kabul River are listed in table B.1.

## Modeling Framework: Principles

The key principles that guide the development and implementation of this framework should:

- take into account the entire Upper Kabul system (Upper Kabul River basin, Logar and Panjshir basins, and key subbasins) continuity but focus on options to supply the city of Kabul
- use an integrated water resources management/ river basin planning framework
- use a *planning* decision support system frame-work to reflect all key relevant water uses (note: although hydropower is not consumptive,

**Table B.1 Key Investment Options for Kabul River Basin**

| Category | Possible investments | Comments |
|---|---|---|
| Reservoirs | ◆ R1: Paghman dam<br>◆ R2: Kajab<br>◆ R4: Tangi Wardag<br>◆ R7: Gat<br>◆ R8: Totumdara<br>◆ R9: Barak<br>◆ R10: Panjshir I (Gulbahar)<br>◆ R11: Baghdara<br>◆ R12: Haijan | Dams have been costed at various sizes and the optimal size of the dams can be determined under various scenarios |
| Groundwater aquifer development | ◆ Tap additional potential of Logar aquifers<br>◆ Tap Panjshir aquifers | **Key assumptions:** (see below) |

Key assumptions:

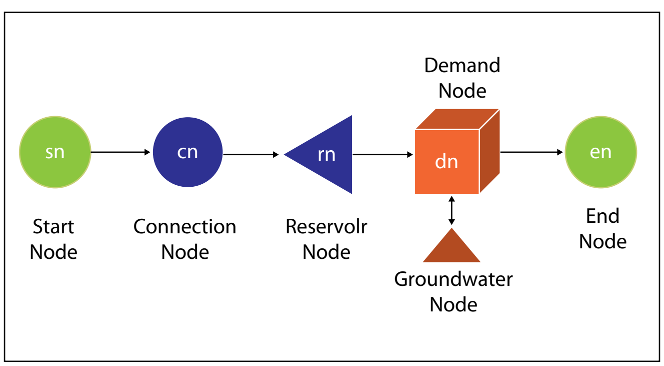
| Usable groundwater capacity | 2005 | 2015 | 2020 |
|---|---|---|---|
| Kabul aquifers | 48% | 100% | 100% |
| Panjshir aquifers | 0% | 50% | 100% |

| Table B.1 Key Investment Options for Kabul River Basin | | |
|---|---|---|
| **Category** | **Possible investments** | **Comments** |
| Conveyance infrastructure | ◆ Connectivity from Panjshir aquifer to Kabul<br>◆ High-level canal for Panjshir surface water to Kabul<br>◆ Low-level canal for Panjshir surface water to Kabul | Connectivities will have costs associated with extraction, treatment, and conveyance |
| Other | ◆ Investments in creating/expanding irrigation areas<br>◆ Complementary investments | The impact of complementary investments can be reflected in the DSS (for example through prices that can be obtained for irrigated farm produce based on improved market access) |

it does impact timing of releases and should be included)

- consider existing and accessible data availability
- use a simple, interactive, and highly visual modeling framework
- use an overarching economic framework with adequate robustness of technical relationships in a basin context
- be able to reflect key benefits, costs, and criteria
- use easily available analytical tools
- facilitate ease of sensitivity analysis
- build upon previous work available
- be flexible, modular, and expandable

**Figue B.1:** Schematic for Upper Kabul River Basin




## Schematic

A critical precursor to the modeling framework is to develop a workable and useful schematic for the Upper Kabul River basin. This is to be composed of simple primitives such as different nodes, shown in figure B.1, and connectors illustrating the connection between them. The schematic has to be as simple as possible to reflect data availability at this preliminary stage of scoping options. However, it should be detailed enough to represent the key joint multipurpose options and their impacts.

## Key Data Required

The analytical framework to be developed would include the following kinds of basic information about the system:

## Modeling Framework

The modeling framework proposed initially for this scoping study is a simple economic optimization in a basin context. This includes the following objectives and constraints:

Some of these constraints are shown visually in figure B.2. In addition, there are a number of other constraints associated with:

- return flow
- hydropower generation
- minimum demand for domestic, environmental, and other uses

| System definition | Irrigation |
|---|---|
| ◆ type of node n (source, demand, connection, reservoir, end, etc.)<br>◆ connection matrix from (define network)<br>◆ connection for return<br>◆ conveyance loss<br>◆ efficiency of water use in various sectors<br>◆ fraction of return flow | ◆ maximum irrigable area at n<br>◆ crop yields (tons per ha)<br>◆ gross water requirement for crop c at time t (mm)<br>◆ crop calendar matrix (1 = crop present; 0 = crop absent)<br>◆ current cropping pattern in system (ha)<br>◆ min cropping constraint for system (ha)<br>◆ max cropping area constraint for system (ha)<br>◆ crop yield of crop c at location n (tons per ha)<br>◆ crop location constraint matrix for crop c at n |
| **Hydrological** | **Municipal and industrial** |
| ◆ inflow at start node n at time t (MCM)<br>◆ additional inflow from independent catchment at reservoir n (MCM)<br>◆ evaporation at node n (mm)<br>◆ sustainable yield of groundwater at n (MCM) | ◆ population/demand growth<br>◆ monthly domestic demand at node n in year y (MCM)<br>◆ load capacity/factor of utilization<br>◆ min/max hydropower generation (MWH) |
| **Reservoirs** | **Hydropower** |
| ◆ live capacity of reservoir at n (MCM)<br>◆ dead storage of reservoir at n (MCM)<br>◆ area storage coefficients<br>◆ elevation storage coefficients<br>◆ percentage capacity left in year y at reservoir n (due to siltation) | ◆ hydropower generation capacity (MWH)<br>◆ efficiency of production/transmission |
| **Economic** | **Environment/social** |
| ◆ net benefits of crop c grown at location n (USD per ton)<br>◆ hydropower benefits (USD/MWH)<br>◆ flood benefits<br>◆ reservoir cost storage coefficients<br>◆ total cost of moving water from n to n1<br>◆ transmission costs (USD per MWH)<br>◆ groundwater pumping costs (USD/$m^3$)<br>◆ costs of sediment management (USD/ha) | ◆ water quality for any selected pollutants (mg/l and loading)<br>◆ environmental flow requirement in selected stretches at time t<br>◆ environmental and social implications of various options (where available) |

## OBJECTIVE FUNCTION

*Maximize*

$$Net\_Benefits, Z = Irrigation\_Benefits \sum_{c}\sum_{dn}(AREA_{c,dn} * YIELD_{c,dn} * NETBEN_{c,dn})$$

$$+Power\_Benefits \sum_{rn} HPGEN_{rn,t} * HPBEN_{rn,t}$$

$$-Costs(storage, pumping, conveyance, treatment)$$

Subject to: Constraints (technical/continuity, resource)

Key decision variables (computed by model):

| | |
|---|---|
| Z | Objective function value |
| Q(n,n1,t) | flow from n to n1 at time t |
| QD(n,d,t) | qty demanded at n for demand type d at time t |
| SR(n,t) | storage in reservoir n at time t |

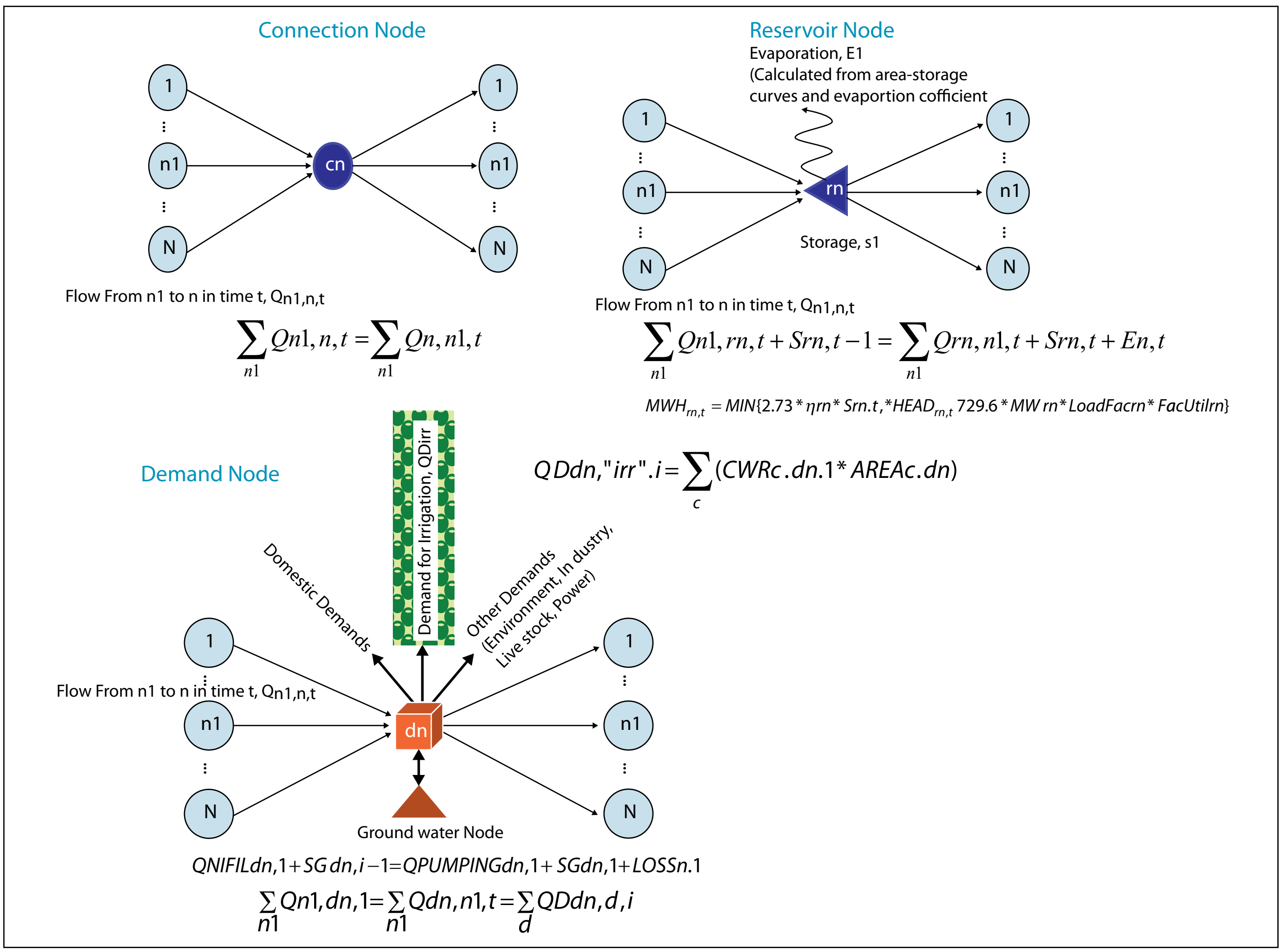
| | |
|---|---|
| SRMAX(n) | max storage in reservoir n (could be specified or optimized) |
| SGW(n,t) | storage in groundwater at n in t |
| RFS(n,n1,t) | return flow from sys use at n to n1 at time t |
| AREA(c,n) | area at n with crop c |
| HPGEN(n,t) | hydropower generation at each location n in time t |

- crop water requirements for irrigation
- capacity constraints: reservoir storage, pumping, conveyance, hydropower
- minimum/maximum area constraint for irrigation
- capacity constraints: groundwater (will be revisited, depending on importance in this basin for the scenarios considered and information available)
- budget constraints
- special scenario constraints

# Scenarios

The key scenarios that are considered include sensitivity analyses on:

**Figure B.2:** Constraints in Modeling Framework



| Table B.2 Parameters and Assumptions Used to Define Scenarios | |
|---|---|
| **Scenario parameter/assumption** | **Value** |
| Year | 2020 |
| Cost of SW treatment ($/m$^3$) | 0.1 |
| Cost of GW treatment ($/m$^3$) | 0.03 |
| Cost of Kabul effluent treatment ($/m$^3$) | 0.15 |
| Cost of Kabul effluent agr reuse ($/m$^3$) | 0.05 |
| Pumping energy cost ($/m$^3$) | 0.0123 |
| % of inflow | 100 |
| Kabul % sewer coverage | 60% |
| Kabul return flow % | 60% |
| Irrigation return flow % | 30 |
| Irrigation demand % (Logar) | 100 |
| Irrigation demand % (Panjshir) | 100 |
| EFR (Kabul River) (m$^3$/s) | 1 |
| Waterfowl sanctuary (ha) | 1000 |
| Addnl. yield multiplier | 1 |
| R1: Paghman dam | TRUE |
| R2: Kajab | TRUE |
| R4: Tangi Wardag | TRUE |
| R7: Gat | TRUE |
| R8: Totumdara | TRUE |
| R9: Barak | TRUE |
| R10: Panjshir I (Gulbahar) | TRUE |
| R11: Baghdara | TRUE |
| R12: Haijan | TRUE |
| Panjshir GW | TRUE |
| Panjshir SW HL | TRUE |
| Panjshir SW LL | TRUE |
| Logan SW | TRUE |
| Paghman SW | TRUE |
| Karga SW | TRUE |
| Urban demand multiplier | 100% |
| Urban distribution loss % | 25% |
| Usable GW cap-Kabul | 100% |
| Usable GW cap-Panjshir | 100% |
| Min crop pattern (% of current) | 80% |
| Max crop pattern (% of current) | Unrestricted |

- different years in the future (for example, 2005, 2015, 2020) with different demand (including population growth) assumptions
- discount rates
- cropping pattern assumptions/constraints
- turning off and on or scheduling various reservoir/connectivity options
- different sizes of key large reservoir options
- low, average, and high flows
- cost variations/assumptions

Additional criteria (for example, other environmental/social issues such as resettlement and rehabilitation requirements and cost, political, regional, budgetary/financial, and other objectives and constraints) can be introduced over time as required. A typical set of key parameters/assumptions currently used to define scenarios are shown in table B.2.

It is possible to vary an extensive number of parameters even in this initial DSS; however, to facilitate the interaction with decision makers, it would be useful to limit the variation across scenarios to a few key parameters, determined after running many scenarios, to determine the sensitivity of results to parameters. The computerized DSS developed helps in the interactive choice of scenarios and facilitates comparison of scenarios.

## Key Outputs

The key output metrics that can be used to compare various scenarios include information on:

- economic information (total net benefit, benefit and cost breakdowns)
- flows
- water supply to Kabul from various sources
- reservoirs built and sizes in scenario
- storage/release characteristics of reservoirs
- groundwater pumping patterns of reservoirs
- shadow prices of water at various nodes (the change in the objective of net benefit for an extra unit of water at that node, reflecting a water scarcity measure)

A typical set of key metrics to define key outputs for scenario comparison includes those listed in Table B.3.

| Table B.3 Key Output Metrics for Scenario Comparison | |
|---|---|
| **Key output metrics** | **Value** |
| Total net benefits ($m) | 467.9 |
| Gross benefits ($m) | 676.3 |
| Supply costs ($m) | 49.4 |
| Storage costs ($m) | 158.9 |
| Surface water supply to Kabul (MCM/yr) | 1.2 |
| Groundwater supply to Kabul (MCM/yr) | 181.2 |
| Total irrigated area (ha) | 165590 |
| Total storage (Kabul + Logar) (MCM) | 259.6 |
| Total storage (Panjshir) (MCM) | 0 |
| Environmental flow through Kabul ($m^3/s$) | 1.96 |
| Max R1: Paghman dam (MCM) | 1.3 |
| Max R2: Kajab (MCM) | 0 |
| Max R4: Tangi Wardag (MCM) | 123.1 |
| Max R7: Gat (MCM) | 21.3 |
| Max R8: Totumdara (MCM) | 0 |
| Max R9: Barak (MCM) | 0 |
| Max R10: Panjshir I (Gulbahar) (MCM) | 0 |
| Max R11: Baghdara (MCM) | 0 |
| Max R12: Haijan (MCM) | 113.9 |

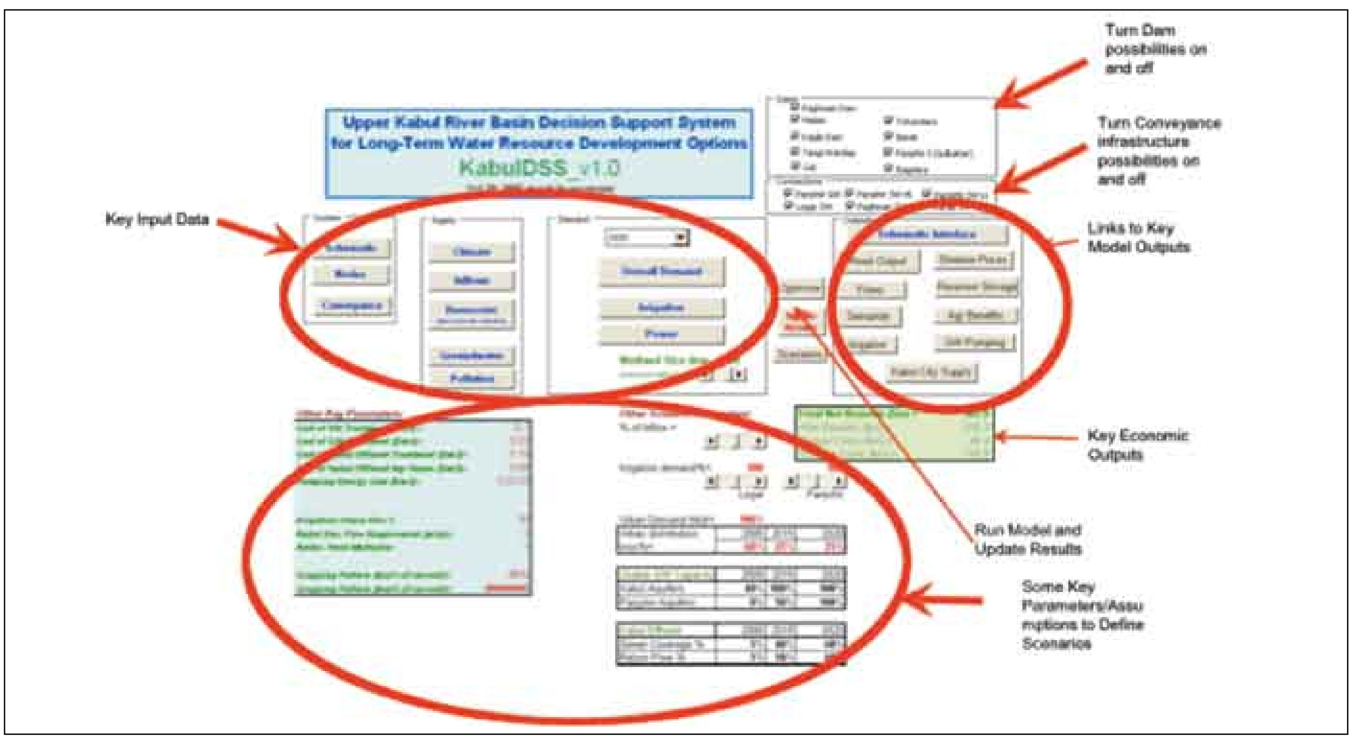
It is possible to display the results in great detail. However, it is important to strike the right balance between providing relevant information to decision makers and creating an information overload that can paralyze decision making. Also, the computerized DSS provides a good opportunity to group and display results visually and in detail, with custom-designed interfaces for each set of decisions to be made and each decision maker's interests.

## Interface

It is crucial to have a logical interface customized to the needs of decision makers. In this case, a graphical user interface was created to assist the user to quickly navigate through the system, both in specifying scenarios and in visualizing results after updating the models. The interface developed here, which can be further streamlined as actual users interact with this model, is indicated in figure B.3.

The interface primarily uses a spreadsheet (Microsoft Excel, which should be ubiquitous) and an optimization package (the Generalized Algebraic Modeling System (GAMS), whose development was financed by the World Bank two decades ago for investment planning in the Indus basin

**Figure B.3:** Interface for System Navigation



and which has been updated frequently since at http://www.gams.com/).

The DSS has been written such that Visual Basic Macros in Excel reads relevant portions of the spreadsheet workbook, based on the data there and scenarios interactively defined, and writes the *entire* GAMS code (a text file), which is then processed in GAMS. This results in many output text files that are read back into Excel with other Excel-based Visual Basic Macros, creating a seamless visual interface (including tables, schematics, and graphs) for inputs and outputs that can be further customized according to preferences. A popular package such as Excel was chosen to allow for ease of data input and pre/post processing, as well as more widespread use, customization, and further development of this tool. The GAMS model is also self-documenting (appendix C).

## Potential Variations/Extensions

This initial simple analytical tool for rapid scoping of Kabul water supply options could continue to evolve according to data availability and needs. These include:

- consideration of multiple time period sequences (currently snapshots of, say, 2005, 2015, 2025)
- consideration of smaller time steps (currently monthly)
- simulation (simple or stochastic) modeling connected to this optimization model
- detailed subsector models
- estimation of key parameters using remote sensing
- GIS interfaces for analysis
- structured stakeholder process to help improve initial scoping exercise
- changing focus to overall integrated water resources management and basin planning exercises rather than only Kabul water supply (although this tool has been developed in an integrated water resources management/basin framework)
- interfacing with operational models

## Risks and Limitations

There are several risks that need to be recognized as limitations in using the outputs of this analytical framework. These need to be effectively recognized and managed as far as possible and include:

a. **Data limitations** ("GIGO"). Best accessible information from prior studies used to make this DSS currently (a) **too simplified** – need to consider more scenario options, more output metrics; consideration of smaller time steps and multiyear sequences; and (b) **too complex** – analytical framework should not outpace data, institutional capacity.

b. **Adequate reflection of economic, environmental, social, and technical considerations.** In particular, the knowledge base for some of the environmental and social implications of various options is weak and needs strengthening.

c. **Consideration of all key alternative options.** The options considered here will evolve, especially in multistakeholder settings.

d. **Limited consultation at this stage.** This needs to evolve into a structured participation process facilitated with analytical tools.

e. **DSS not used to actually better inform decisions.**

These risks need to be managed by (a) improving the interaction with various stakeholders, (b) improving ownership by locating further model development and use in an appropriate institutional home in Afghanistan, and (c) continuing to slowly make the model as reflective of reality as needed to support the kinds of decisions to be made.

## Expected Outputs

The key outputs that are expected from the use of this analytical framework include:

- organized integrated knowledge base for the Upper Kabul River basin (working schematic, climate, water resources supply, demands, management options, irrigation, and hydropower) and key gaps in the knowledge base

- simple decision support modeling tool for Upper Kabul water supply options analysis and making more informed decisions

- application of output metrics to evaluate options/ scenarios (for example, net benefits for selected options/scenarios)

- determination of sensitivity to various assumptions/ scenarios and the value of additional information, indicating the need for further targeted studies

- usefulness as a tool to facilitate interactive, structured stakeholder participation

Eventually, the kinds of questions that the framework should be able to help answer to assist the scoping include:

- How is Kabul best supplied, given various water-related objectives, constraints, decision options, and likely scenarios?

- What benefits/concerns result from various options when analyzed in a basin context?

- What options appear promising in improving total net benefit to the region (and other criteria)?

- What is the sensitivity of various options to key parameters (hydrological, economic, and financing)?

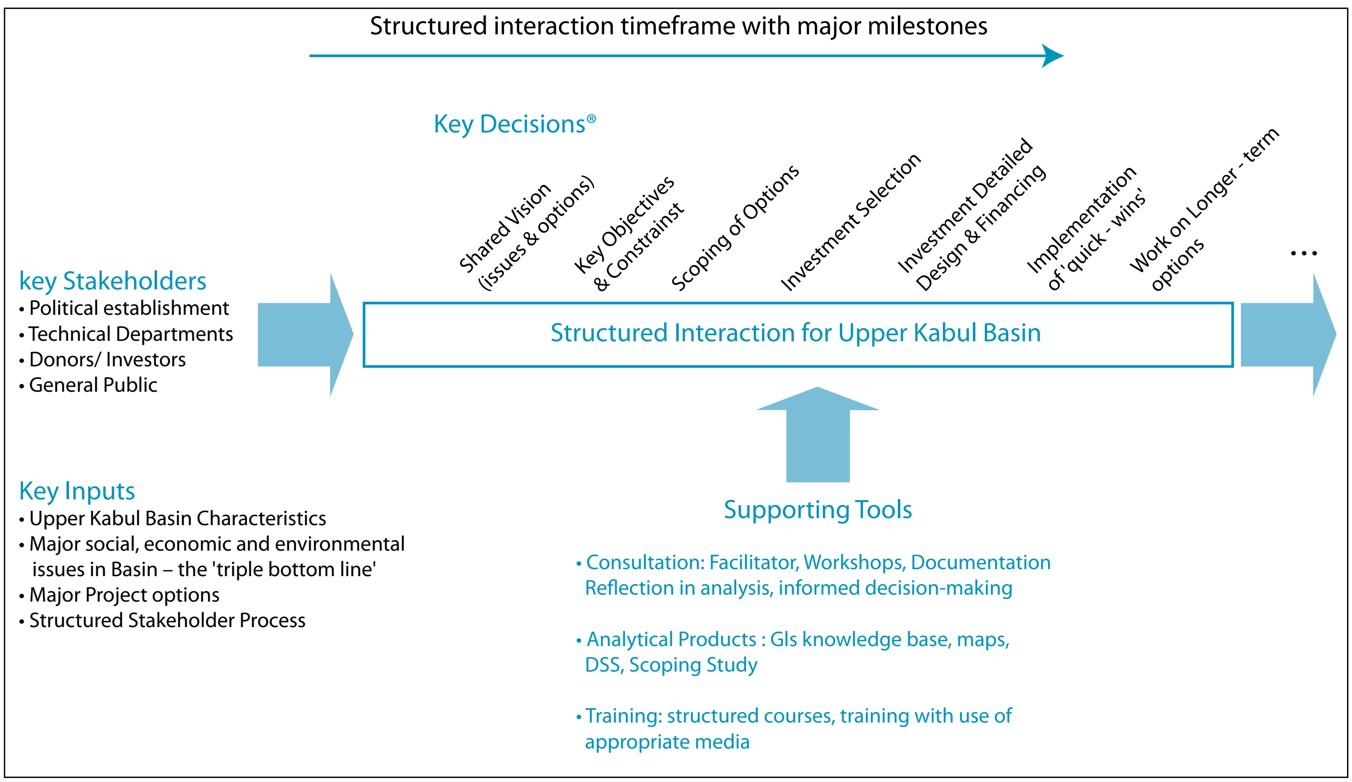
- What are the key uncertainties in the system that need to be investigated further?

- What are the benefits of early informed decisions and costs of inaction?

## Structured Stakeholder Process

This analytical framework would be best utilized if it is not a stand-alone process, but is part of a structured participation process that involves all stakeholders in decision making. Such a process is shown schematically in figure B.4.

**Figure B.4:** Structured Stakeholder Process with Analytical Facilitation for Decision Support



# Appendix C. Detailed DSS Model Structure

## Sets (Subscripts)

n,n1 nodes (with subsets)

sn start nodes

cn confluence or connection nodes

dn demand nodes

rn reservoir nodes

an aquifer nodes

en end nodes

t = months

d = system demand type (domestic, irrigation, environment, livestock, power, industry)

c = crop type (wheat, maize, rice, alfalfa, grapes, vegetables, melons, orchards, cotton)

y = year (2005, 2015, 2020)

## Key Parameters

NODE TYPE(n) type of node n (source, demand, connection, reservoir, end, etc.)

CLTYPE(n) cropping location type of node n

CONNECT(n,n1) connection matrix from n to n1 (to define network)

CSTLINK(n,n1) total cost of moving water from n to n1

RCAP(n) live capacity of reservoir at n (MCM)

SRDEAD(n) dead storage of reservoir at n (MCM)

$AS_0$(n) area storage coeff 0

$AS_1$(n) area storage coeff 1

$AS_2$(n) area storage coeff 2

$CS_0$(n) cost storage coeff 0

$CS_1$(n) cost storage coeff 1

$CS_2$(n) cost storage coeff 2

STORCST(n) cost of storage (USD per $m^3$)

GWMAX(n) sustainable yield of groundwater at n (MCM)

AMAX(n) maximum irrigable area at n

QE(n) quantity of effluent at node n (MCM per month)

CE(n) concentration of effluent at node n (mg per l)

NETBEN(c) net benefit by crop (USD per ton)

Yield(c) crop yields (tons per ha)

EFFDOM(y) efficiency of domestic water use

QINFLOW(n,t) inflow at start node n at time t (MCM)

CWRL(c,t) gross water requirement for crop c at time t in Logar area (mm)

CWRP(c,t) gross water requirement for crop c at time t in Panjshir area (mm)

CROPCALL(c,t) crop calendar matrix in Logar area (1 = crop present; 0 = crop absent)

CROPCALP(c,t) crop calendar matrix in Panjshir area (1 = crop present; 0 = crop absent)

GWPCOST(n,t) groundwater pumping costs (USD per $m^3$)

CPSYS(n,c) current cropping pattern in system (ha)

CPMIN(n,c) min cropping constraint for system (000 ha)

CPMAX(n,c) max cropping area constraint for system (000 ha)

YIELD1(n,c) crop yield of crop c at location n (tons per ha)

NETBEN1(n,c) net benefits of crop c grown at location n (USD per ton)

ECOEFF(n,t) evaporation at node n (mm)

QDDOM(n,y) monthly domestic demand at node n in year y (mm)

QDENV(n,t) environmental requirement at node n at time t

QIR(n,t) Additional inflow from independent catchment at reservoir n (MCM)

SILTFAC(n,y) percentage capacity left in year y at reservoir n (due to siltation)

FCONLOSS(n,n1,t) conveyance loss fraction in flow from n to n1 at time t

CROPCAL(c,n,t) crop calendar matrix

CWR(c,n,t) gross water requirement for crop c at time t (mm)

CRPLOCS(c,n) crop location constraint matrix for crop c at n

DEMLOC(n,d) demand location of type d at node n

GWCH(n,t) groundwater net inflow (change) at n in t

FQGNS(n,t) fraction of AGR water recharged into gw – nonsys

FRFS(n,n1,t) fraction of return flow from n to n1 in t

QLOSS(n,t) net loss at node n at time t

DISLOSS(n,d) distribution losses at node n for use d (fraction)

EFFDIV(n) efficiency of irrigation diversion (already accounted for)

EFFGW(n) efficiency of diversion

RFSCON(n,n1) connection for return flow from node n to n1 – system

HPCAP(n) maximum hydropower generation installed capacity at n

HPBEN(n,t) net benefit of hydropower from n in time t (m USD per MWH)

## Key Variables

| | |
|---|---|
| Z | objective function value (m USD) |
| Q(n,n1,t) | flow from n to n1 at time t (MCM/month) |
| QD(n,d,t) | qty demanded at n for demand type d at time t (MCM/month) |
| SR(n,t) | storage in reservoir n at time t (MCM) |
| SRMAX(n) | max storage in reservoir n (MCM) |
| SGW(n,t) | storage in groundwater at n in t (MCM) |
| RFS(n,n1,t) | return flow from sys use at n to n1 at time t (MCM/month) |
| AREAS(c,n) | area at n with crop c (hectares) |
| HPGEN(n,t) | hydropower generation at n in time t (MWh) |
| MINOHP(t) | minimum hydropower generation required at time t (MWh) |
| MAXOHP(t) | maximum hydropower generation required at time t (MWh) |

# Key Model Equations

**Maximize Net Benefit Z**

$$Z = \sum_{n}\sum_{c} \mathrm{NETBEN}_{c} * \mathrm{YIELD}_{c,n} * \mathrm{AREAS}_{c,n} \rightarrow AgriculturalBenefits$$
$$+\sum_{n}\sum_{t} \mathrm{HPGEN}_{n,t} * \mathrm{HPBEN}_{n,t} \rightarrow HydropowerBenefits$$
$$-\sum_{\mathrm{n}}\sum_{n1}\sum_{t} \mathrm{CSTLINK}_{n,n1} * \mathrm{Q}_{n,n1,t} \rightarrow SupplyCosts(extraction, treatment, conveyance)$$
$$-\sum_{\mathrm{rn}} CS_{0_{rn}} + CS_{1_{rn}} * (SRMAX_{rn} + SRDEAD_{rn}) + CS_{2_{rn}} * (SRMAX_{rn} + SRDEAD_{rn})^2 \rightarrow StorageCosts$$

**Continuity Constraint (start nodes)**

$$\sum_{n1} Q_{sn,n1,t} = \mathrm{QINFLOW}_{sn,t} \cdots \forall(sn,t)$$

**Continuity Constraint (continuity nodes)**

$$\sum_{n1} Q_{n1,cn,t} + \sum_{n1} RFS_{n1,cn,t} = \sum_{n1}[Q_{cn,n1,t} * (1 + FCONLOSS_{cn,n1,t})] \cdots \forall(cn,t)$$

**Continuity Constraint (demand nodes)**

$$\sum_{n1} Q_{n1,dn,t} + RFS_{n1,dn,t} = \sum_{n1} Q_{dn,n1,t} * (1 + FCONLOSS_{dn,n1,t}) + \sum_{d} QD_{dn,d,t} \cdots \forall(dn,t)$$

**Continuity Constraint (groundwater nodes)**

$$\sum_{n1} Q_{n1,an,t} + GWCH_{an,t} + SGW_{an,t-1} = \sum_{n1} Q_{an,n1,t} * (1 + FCONLOSS_{an,n1,t}) + SGW_{an,t} \cdots \forall(an,t)$$

**Continuity Constraint (reservoir nodes)**

$$\sum_{n1} Q_{n1,rn,t} + QIR_{rn,t} + SR_{rn,t-1} + RFS_{n1,rn,t} = \sum_{n1} Q_{rn,n1,t} * (1 + FCONLOSS_{rn,n1,t}) + SR_{rn,t}$$
$$+EVAP_{n,t} \cdots \forall(rn,t)$$

**Return Flows**

$$RFS_{n,n1,t} = \sum_{d} FRFS_{n,n1,t} * QD_{n,d,t} \cdots \forall(n,n1,t)$$

**Groundwater Sustainable Yield Constraint**

$$SGW_{an,t} \le GWMAX_{an} \cdots \forall(an,t)$$

**Pumping Constraint**

$$\sum_{n1} Q_{an,n1,t} \le MaxMonthlyGroundwaterYield_{an} \cdots \forall(an,t)$$

**Domestic Demand Constraint**

$$QD_{dn,"DOM",t} = QDDOM_{dn,y} * (1 + DISLOSS_{dn,"DOM"}) \cdots \forall(dn,t\ \&\ selected\_year - y)$$

**Environmental Demand Constraint**

$$QD_{dn,"ENV",t} = QDENV_{dn,y} \cdots \forall (dn,t \,\&\, selected\_year - y)$$

Also, **Environmental Flow Requirement Constraints** at selected segments (e.g. through Kabul)

**Crop Water Requirements**

$$QD_{n,"IRR",t} \Big/ EFFDIV_n = \sum_c \frac{AREAS_{c,dn} * CWR_{c,dn,t}}{10^5} \cdots \forall (rn,t)$$

**Irrigated Area Constraints (allowing for multiple crops in a year where possible)**

$$AREAS_{c,dn} * CROPCAL_{c,dn,t} \leq AMAX_{dn} \cdots \forall (dn,t)$$

**Minimum Cropping Constraints**

$$AREAS_{c,dn} \geq CPMIN_{n,c} * 10^3 \cdots \forall (c,dn)$$

**Maximum Cropping Constraints**

$$AREAS_{c,dn} \leq CPMAX_{n,c} * 10^3 \cdots \forall (c,dn)$$

**Storage Limits**

$$SR_{rn,t} \leq SRMAX_{rn} \cdots \forall (rn,t)$$

**Reservoir Sizing Constraint**

$$SRMAX_{rn} \leq RCAP_{rn} * SILTFAC_{n,y} \cdots \forall (rn)$$

**Hydropower Constraints**

$$HPGEN_{n,t} \leq 729.6 * \mathrm{HPCAP}_n * \mathrm{EFF}_n \cdots \forall (n,t)$$

$$HPGEN_{n,t} \leq 2.73 * 0.9 * \mathrm{MAXHEAD}_n * \sum_{n1} \mathrm{Q}_{n,n1,t} \cdots \forall (n,t)$$

$$\sum_n \mathrm{HPGEN}_{n,t} < MAXOHP_t$$

$$\sum_n \mathrm{HPGEN}_{n,t} > MINOHP_t$$

**Reservoir Choice Constraints** (based on turning proposed reservoirs on and off in scenario defined)

**Infrastructure Link Constraints** (based on turning proposed conveyance links on and off in scenario defined)

**Non-Negativity Constraints**

Q≥0; QD≥0; SR≥0, SRMAX≥0; SGW≥0, RFS≥0, AREAS≥0, HPGEN≥0

***Note:*** This formulation can be easily modified to include additional options, decision variables, objectives, and constraints. For example, demand curves can be included for large demands (e.g. mining) where there could be significant demand elasticity. An intertemporal optimization can also be carried out when more time series information becomes available. This optimization approach can also be used synergistically with other modeling approaches (e.g. system simulation, rainfall-runoff models, water balance models, water quality models, stochastic approaches) to explore other facets of the water system.

# Appendix D. Example Application of Consequence Table

Figure D.1 represents the application of a consequence table to evaluate alternative scenarios with respect to a set of planning objectives, criteria, and measures similar to those shown in section 3.5.

The DSS is used to determine the value for each measure for each scenario and the resulting value is placed in the corresponding cell, as shown in figure D.1. To use the table, a Base Case or focus scenario must be chosen. Any scenario may be chosen, and one can easily cycle through the entire set of scenarios one after the other, comparing each scenario to all the others. In the table below scenario D has been chosen as the focus scenario against which all the other scenarios are compared. The underlying model colors the cells for each of the nonfocus scenarios according to the scheme shown at the bottom of the table:

- *Red*, if the value in the cell is significantly worse than the value for the focus scenario;
- *Yellow,* if the value in the cell is not significantly different than the value for the focus scenario;
- *Green,* if the value in the cell is not significantly different than the value for the focus scenario.

It is evident from the results shown in figure D.1 that the selected focus scenario (D) is superior to all other scenarios by nearly all measures, with the possible exception of scenario C.

Scenarios D and C are not significantly different in many respects, including agricultural benefits; employment generation; poverty, public health, and food security impacts; and impacts on navigation and biodiversity. They also represent approximately the same qualities with regard to regional negotiation and political impact (including the issue of instability). The differences are displayed in table D.1.

The difference between these two scenarios is that one (C) has less risk, while the other (D) has larger economic benefit. The tradeoff is thus whether to accept more risk for extra economic benefit. Figure D.1 shows this incremental benefit is greater than $2 billion per year However, note that C involves one dam, and D 4 dams. This suggests that, given the long gestation time of these large infrastructure projects, the incremental benefit from scenario D may accrue much later than that from scenario C, in which the present worth of this incremental benefit may be smaller for some stakeholders, particularly those who are risk averse, and this might tip the balance in favor of scenario C.

In this example the differences between the two most favorable scenarios involved a relatively simple comparison based on similar sets of objectives.

| Choosing C rather than the Focus Scenario D | |
|---|---|
| **Results in more of** | **But less of** |
| Fewer resettled people<br>Greater protection of cultural sites<br>Lower financial risk<br>Lower technical risk | Power generation<br>Flood benefits<br>Water supply benefits<br>Watershed management<br>Greenhouse gases credits<br>Regional interdependence<br>Regional trade<br>Growth pole potential |

**Figure D.1:** Application of a Consequence Table to an Evaluation of Alternative Scenarios

Focus Scenarios ...> D (B+4 Dams) ▼

| Illustrative Template for Consequence Tale to Evaluate Scenarios | | | | | Altemative Scenarios | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Type** | **Criteria** | **Indicator** | **Preference (H=higer is better, L=lower is better)** | **Units** | **A (Base Case)** | **B (Low Level Dev)** | **C (B+1Dam)** | **D (B+4 Dams)** | **E (B+Basin2)** |
| Economic | Agriculture | Agricultural benefits | H | billion $/year | 4.93 | 5.50 | 9.00 | 11.00 | 7.00 |
| | Power | Power benefits | H | billion $/year | 0.50 | 0.70 | 0.98 | 1.36 | 0.72 |
| | Flood Protection | Expected Flood damages | L | billion $/year | 0.30 | 0.28 | 0.18 | 0.05 | 0.26 |
| | Employment | Total new F/T jobs | H | billion # jobs | - | 0.30 | 0.50 | 0.65 | 0.31 |
| Social | Low Income Effect | Change in no. people above $1/day | H | billion # people | - | 0.60 | 1.00 | 1.30 | 0.50 |
| | Public Health | Incidence of water related disease | L | billion DALYs | 10.00 | 10.00 | 9.00 | 8.00 | 10.00 |
| | Resettlement | People relocated | L | thousands # people | - | 25.00 | 26.00 | 125.00 | 150.00 |
| | Drinking Water | New people with adequate access to safe water | H | additional million # people | - | 2.00 | 3.00 | 4.00 | 2.20 |
| | Food Security | Percent of pop with cereal needs met | H | % | 0.75 | 0.77 | 0.82 | 0.90 | 0.78 |
| | Navigation | Navigable river reaches | H | kn-months | 25.000 | 25.000 | 40.000 | 50.000 | 30.000 |
| Environmental | Aquatic/wetland biodiv | Area of aquatic habitat | H | thousand sq km | 10.00 | 9.90 | 9.90 | 9.90 | 4.00 |
| | Watershed management | Area of well managed watershed | H | thousand hectares | 20.00 | 50.00 | 350.00 | 500.00 | 60.00 |
| | Water Quality | Water quality index | H | unitless | 0.80 | 0.75 | 0.85 | 0.90 | 0.75 |
| | Saline water intrusion | Flow to Med Sea | H | bcm | 13.00 | 10.00 | 13.00 | 14.00 | 11.00 |
| | Greenhouse gases | GHG emission offset | H | million tonnes/ year | - | 0.70 | 7.50 | 22.00 | 2.00 |
| | Cultural sites | Sites impacted | L | # sites | - | - | - | 2.00 | 1.00 |
| Regional/Implementation | Regional Interdependence | Degree of joint ownership and management | H | scale | 1.00 | 1.00 | 3.00 | 4.00 | 1.00 |
| | Regional Trade | Value of bilateral trade | H | billion $/year | 1.00 | 1.00 | 1.50 | 3.00 | 1.00 |
| | Growth Pole Potential | Number of equivalent centres | H | # equiv centres | - | - | 1.00 | 4.00 | 0.50 |
| | Negotation Space | Total system losses | L | bcm | 40.00 | 43.00 | 38.00 | 36.00 | 42.00 |
| | Financing Risk | Financing Risk Scale | L | scale | 1.00 | 1.00 | 3.00 | 4.00 | 4.00 |
| | Technical Risk | Technical Complexity Scale | L | scale | 1.00 | 1.00 | 2.00 | 3.00 | 3.00 |
| | Political Instability | Conflict Potential/Instability Scale | L | scale | 1.00 | 1.00 | 1.00 | 1.00 | 3.00 |

| **Focus Alternative** |
|---|
| Significantly Worse Than Focus Alternative |
| Not Significantly Different to Focus Alternative |
| Significantly Better Than Focus Alternative |

# Appendix E. Discussion of Alternative Scenarios

## Results for the Base Case Scenario

Table E.1 summarizes the total investment cost for full development of optimal investment plan for the Base Case scenario (see table 6.1). The Base Case investment plan[54] includes (a) five storage reservoirs with a total storage capacity of 611 million cubic meters, (b) hydroelectric generating capacity of 853 megawatts and energy production of 2,179 gigawatt-hours per year, (c) approximately 182,930 hectares of irrigated agriculture, and (d) one new groundwater source and three new surface water sources for Kabul bulk water supply.

The Base Case storage system (figure E.1) consists of (a) three reservoirs (Kajab, Gat, and Haijan) which regulate the Logar and Upper Kabul subbasin for irrigation, the Aynak opper mine and Kabul bulk water supply (including recharge of aquifer A1); (b) a single storage reservoir in the Panjshir subbasin located at Gulbahar (also called Panjshir I); and (c) a single storage reservoir in the Lower Kabul subbasin on the Konar River (Konar A), as shown in figure 4.1.

| Table E.1 Model Results for Base Case Scenario | |
|---|---|
| **Options** | **Cost (US$ million)** |
| Storage (& run-of-river) | 1,105 |
| Irrigation | 1,098 |
| Kabul water supply | 266 |
| Total | 2,469 |

[54] The Base case water (water supply and environment, mining) and electricity demands are summarized in chapter 4.

Figure E.2 summarizes the sources of Kabul's bulk water supply under the Base Case scenario. Surface water from the Logar-Upper Kabul subbasin is 17 percent of the incremental Kabul bulk water supply and the balance is provided by groundwater from Parwan Province, in the Panjshir subbasin.

Approximately 70 percent of the annual Base Case energy demand (energy exports from and imports to the basin being zero in the Base Case) will be generated from two Lower Kabul River subbasin options (see figure 4.1): (a) at Sarobi II, a high-head run-of-river site on the main stem of the Lower Kabul River located between the upstream existing plants at Naglu and Sarobi I and the downstream

**Figure E.1:** Base Case Storage Reservoirs

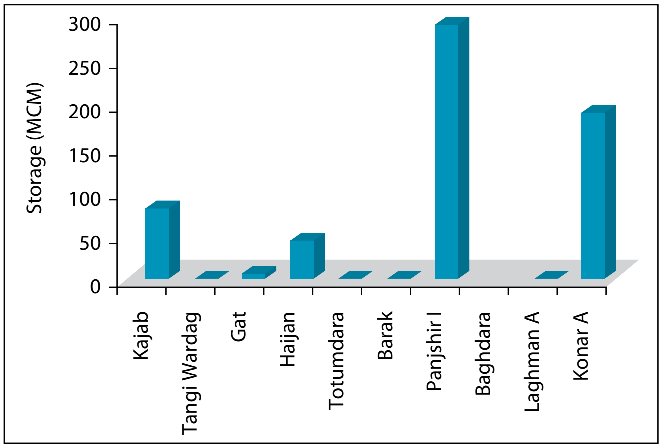


**Figure E.2:** Base Case Sources of Kabul Water Supply

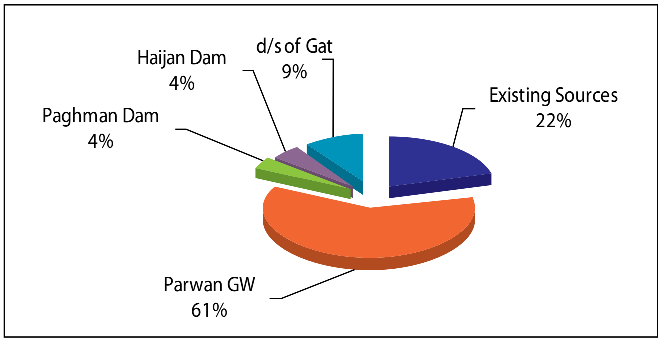
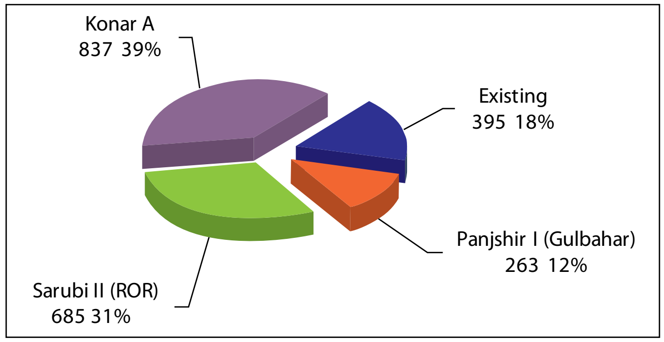



**Figure E.3:** Base Case Sources of Energy Production (GWH/yr)



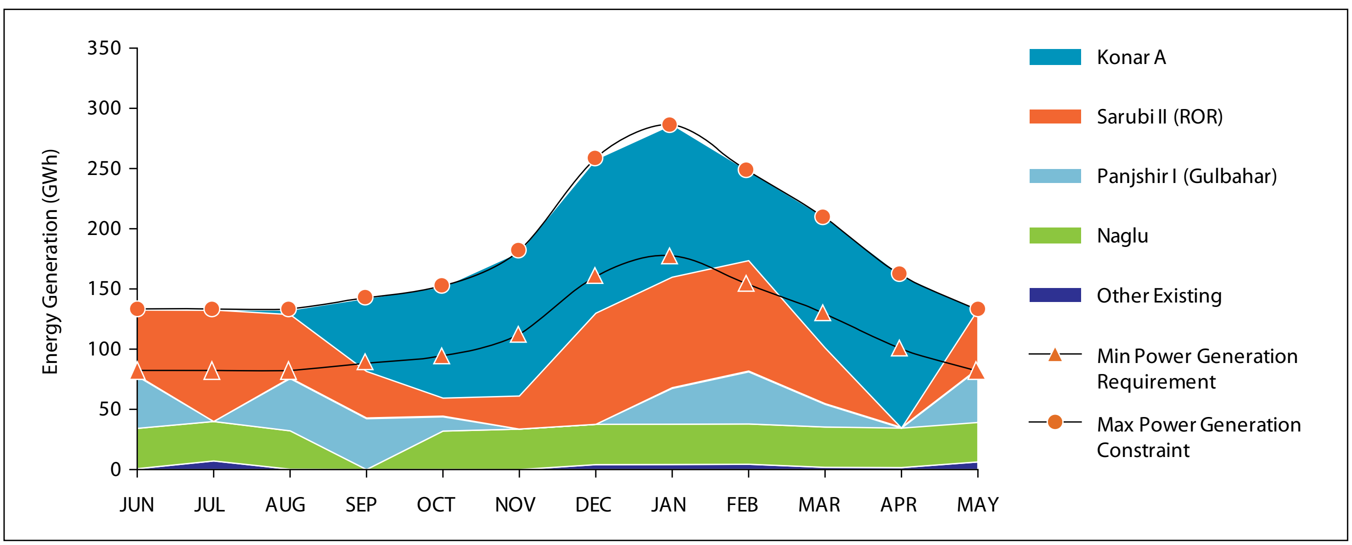

existing plant at Darunta; and (b) a storage reservoir on the Konar River. The remaining demand will be met from existing sources (18 percent) and the storage reservoir on heh Panjshir River at Gulbahar (12%).

The monthly pattern of energy generation by the system is shown in figure E.4 in relation to the minimum and maximum projected energy demand. No hydroelectric generation facilities were included in the costs of the three Logar and Upper Kabul reservoirs, but this could be added during detailed planning, though the energy is not likely to be firm and hence would be of lower value.

With the exception of Konar A, no site generates electricity in all months (figure E.4). The period from August to October, and in some cases up till November, is critical for hydropower options in the Kabul River basin (except for the Konar A option). The major challenge in sequencing the development of these options is to determine how firm generation capacity and energy production can be sustained during this critical period and the peak winter months through the long period of development. Hence, basin simulation studies of interim operations of different development sequences, and levels of capacity that can be staged, will be necessary.

The total installed capacity of the basin hydropower system (figure E.4) is approximately 853 megawatts, while the maximum estimated peak power requirement in January is approximately 632 megawatts (using an energy load factor of 0.63, based on tables 4.2 and 4.3). As the reservoirs, and consequently the dams, are much smaller than the estimate of maximum potential at these sites, some adjustment of hydroelectric power facilities at these dams could result from more detailed longer-term simulation studies of system operation.

**Figure E.4:** Base Case Energy Generation



## Hydrological Risk Scenarios

Droughts are frequent in Afghanistan and in the Kabul River basin, resulting in generally high variability for both groundwater and streamflow (chapter 3). Rivers that drain the Hindu Kush mountain range are generally less variable because their flow depends much more on melting snow and glaciers, but annual snowfall is also notably variable. In these hydrological circumstances, it is wise to consider alternative strategic plans for selected drought or low flow periods rather than mean or average flow conditions. The reliability of bulk water supplies for irrigation, for example, strongly influences farmers' adoption of new, higher-value crops and water-saving irrigation technologies, such as drip irrigation for orchards. Typically, urban water supply requires high bulk supply reliability of 90 percent or more, as does hydropower electricity production. In the latter case, low reliability lowers both the production capacity and the value of hydropower in an electricity system.

The Base Case scenario (table 6.1) is based on annual streamflow that is 90% reliable (a level of annual streamflow availability at each of the key gauging stations that is equaled or exceeded 90 percent of the time), which is equivalent to the one-year drought that occurs on average once in 10 years. These estimates, however, are based on the short hydrological records available (Toosab and RCUWM 2006).

To assess the effects drought on the Base Case (table 6.1), four hydrological risk scenarios are considered

a. Average year, with mean annual streamflows;

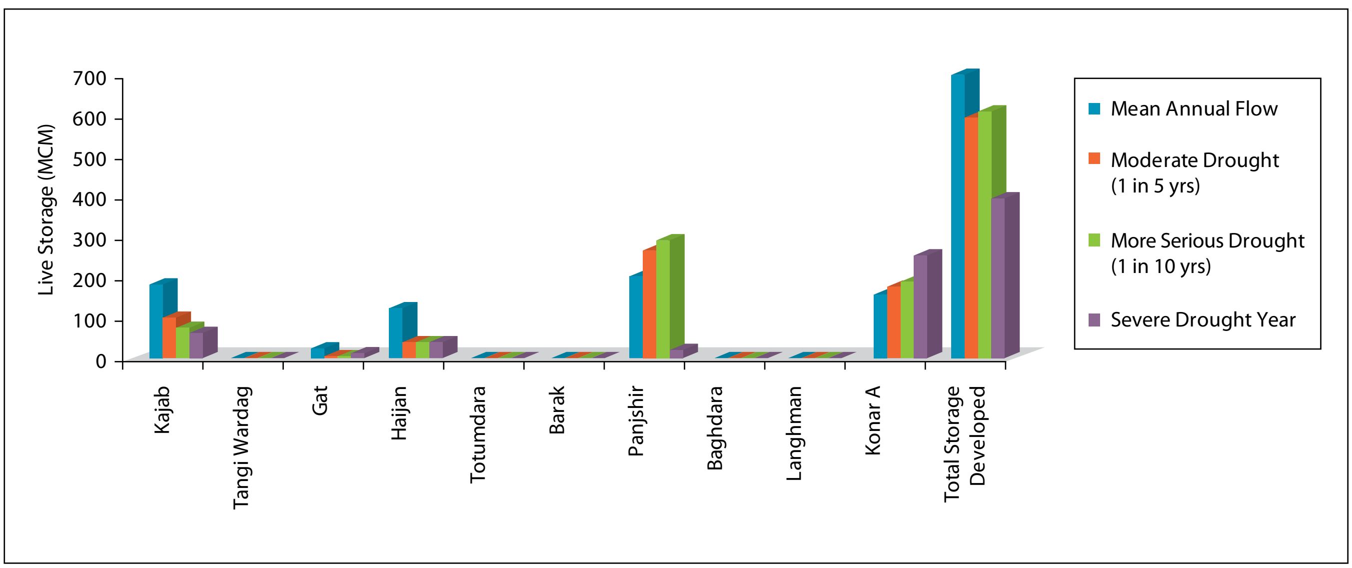
b. Moderate drought year, when streamflows are 80 percent reliable, that is the annual flow is less than these streamflows only once in five years;

c. More serious drought year, when streamflows are 90 percent reliable, that is the annual flow is less than these streamflows only once in 10 years. This is the standard drought and water availability condition adopted for this study;

d. Severe drought year, when streamflows are 95 percent reliable, that is the annual flow is less than these streamflows only once in 20 years.[55]

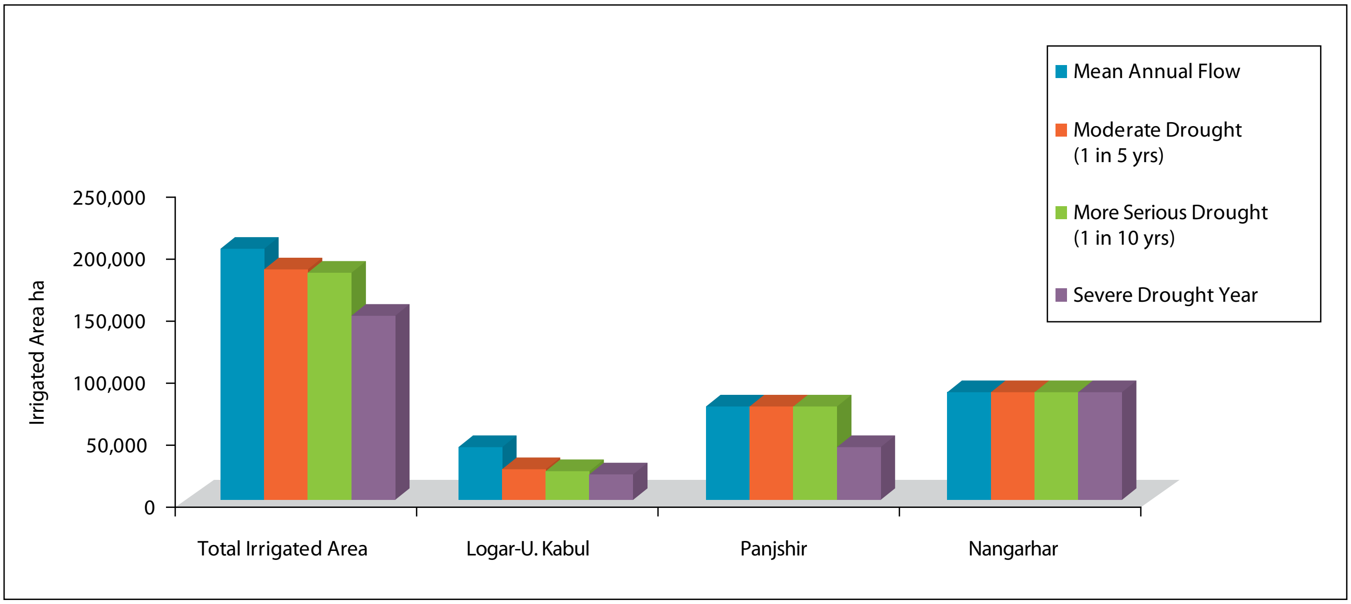
Figure E.5 summarizes the optimal storage options under each of these four different hydrological risk scenarios. The results indicate that the same combination of storage options are optimal under all four scenarios. Energy production in each of these scenarios is sufficient for the maximum level of demand (tables 4.2 & 4.3). The amount of live storage developed generally increases as the severity of the assumed drought conditions increases. The

**Figure E.5:** Base Case Storage Options under Different Hydrologic Risk Options




[55] Annual streamflows would be expected to equal or exceed these values 95 percent of the time on average.

**Figure E.6:** Base Case Irrigated Area under Different Hydrologic Risk Scenarios




exception is the case of the most severe drought scenario under which total storage and the storage developed at Panjshir I decreases. Total storage in the Logar-Upper Kabul subbasin decreases progressively under increasingly severe drought scenarios, as streamflows are severely limited in this subbasin in drought years.[56] (note in table 3.2 that the annual flow from this subbasin under these drought condition ranges from 63% to less than half the mean annual flow).

Figure E.6 summarizes total basin irrigation development and development in the three subbasins under the four hydrological risk scenarios. Irrigation development in the Nangarhar subbasin (Lower Kabul subbasin) remains the same under all four scenarios.[57] Irrigation development in the Panjshir subbasin remains the same as long as there is substantial storage available from the Panjshir I reservoir[58]. Irrigation development in the Logar-Upper Kabul subbasin decreases substantially as soon as a drought scenario is considered, even under the 80 percent reliability scenario[59].

Overall irrigated area declines from the maximum level of development by about 27 percent or 55,238 hectares for the most severe drought scenario (about 17,566 hectares or 8.6 percent for the 80 percent reliable scenario). Hence, a development strategy for irrigation in the Kabul River basin, in terms of the irrigated areas to be developed in the basin and in each subbasin, involves a risk tradeoff. If the maximum area that can be irrigated in the average flow year (203,267 hectares) is developed, then in any year the average expected shortage would leave about 38,800 hectares unserved[60] if full irrigation demand is met in the remaining area[61] (a shortage in terms of area served of about 19 percent). In the Panjshir subbasin the maximum

[56] The Ministry of Energy and Water has been discussing the utilization of carry-over storage (water stored in one year to be used in the next) in both the Logar-Upper Kabul and Panjshir subbasins when potential reservoir capacities are large. Long-term simulation studies would be needed to determine (a) when there is sufficient water to enable this function, (b) how frequently this occurs, and (c) whether the expected benefits are commensurate with the cost of additional storage capacity.

[57] This always equals the maximum potential except for a scenario in which irrigation efficiency is reduced.

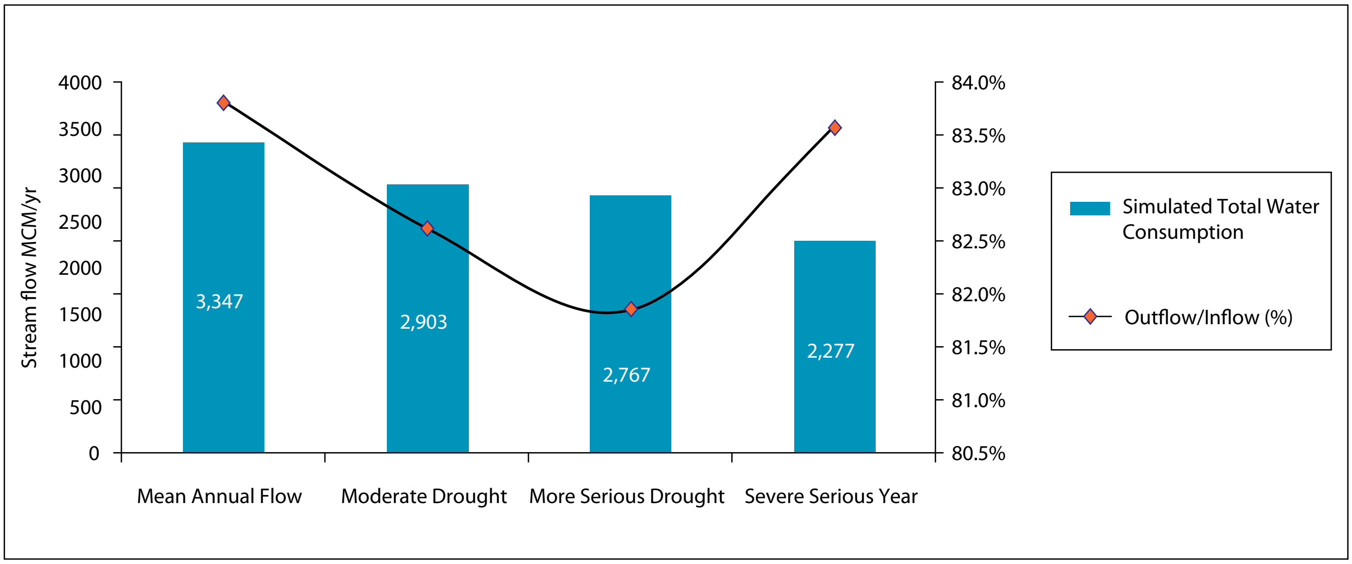
[58] Demands on the storage and outflow from this reservoir are very complex and include: power generation; bulk water supply to Kabul; irrigation; and regulation of streamflows into the downstream storage and run-of-river hydroelectric facilities.

[59] This is close to the often used assumption of 75% reliable water supply for irrigation (that is, water available on average in three out of four years). This assumption enables a larger area to be developed but it is only adequate for traditional agriculture that assumes there is little or no use of cash inputs (new crops with improved or high yielding seed, fertilizer and pesticides, and labor) and hence only marginal integration of irrigated agriculture into the national economy.

[60] This is so if it is assumed that the annual mean is a reasonable first approximation of the median whose reliability is 50 percent. It seems quite likely that the median annual streamflow will be less than the mean annual streamflow because the distribution of annual streamflow is likely to be skewed toward lower values of annual streamflow.

[61] There are other scenarios, discussed in later sections, in which demand in other sectors is high and the irrigated area in the Panjshir subbasin is lower than the maximum even at 90 percent reliability. Hence, determining the risk associated with a particular development strategy also depends on the strategic objectives and options in other sectors.

**Figure E.7:** Base Case Simulated Basin Water Consumption under Different Hydrologic Risk Scenarios




potential area of 75,530 hectares is fully irrigated 90 percent of the time, but the shortage in the one-in-20-year drought event is about 33,450 hectares.[62]

These risks can be mitigated partly by good water management and conservation, and bringing farmers and their organizations, particularly the *mirabs*[63], into the water management institutional framework and decision-making process. This enables them to be fully informed about water availability and participate in deciding how limited water supplies (especially in situations of shortage) will be allocated (or shared) and used. The water allocation and sharing arrangements could vary by subbasin to reflect the relative risk of shortage in each subbasin.[64] The institutional arrangements for river basin management through basin and subbasin councils under the proposed new Water Law are expressly designed to take this participatory water management approach. If properly implemented, this approach would also encourage farmers to adopt technologies and adaptation strategies for maximizing their economic returns based on improved information.

[62] There are many ways farmers could adapt to this level of expected annual shortage of about 20% and still profitably shift a substantial part of their farming to high value crops particularly if they have access to technology and competent advisory services.

[63] *Mirab* is the system of collective farmer maintenance of their traditional irrigation scheme and the name given to the elected manager of the system.

[64] Note the evident importance of improved hydrological monitoring (snow, rainfall, groundwater, and streamflow), streamflow forecasting, and credible analytical planning capability to develop such rules and the effective water management to implement them.

Figure E.7 shows total simulated water consumption in the basin and the ratio of simulated basin outflow and inflow under the Base Case and each of the four hydrological risk scenarios. The maximum water consumption in the four scenarios is about 18 percent of total inflow. Among all other scenarios discussed in this appendix, the maximum water consumption is about 21 percent.

## Storage and Run-of-River Cost Scenarios

One of the most important limitations of the current knowledge base concerning development options in the Kabul River basin is the uncertainty concerning the cost of infrastructure, including dams and hydroelectric facilities, conveyance and pumping stations, and major headworks. Recent data for estimated costs of conveyance are available from the Kabul water supply feasibility study (Beller Consult, Kocks, and Stadtwerk Ettlingen 2004). Recent cost data for a major dam are available from a prefeasibility study completed for the Baghdara dam (see figure 4.1) and hydroelectric facility on the Panjshir River (Fichtner Consulting Engineers 2007). Otherwise, the only cost data available for major infrastructure such as storage or run-of-river hydropower options are found in the Kabul River Basin Master Plan completed in 1978 (Montreal Engineering Company 1978).

For the current study, the costs and other characteristics of all dams, reservoirs and hydroelectric infrastructure were taken from the curves in the Kabul River Basin Master Plan report (Montreal Engineering Company 1978) and extrapolated to 2005 using a factor of 2.37, including costs for Baghdara. These extrapolated Kabul River Basin Master Plan cost data were converted to annual unit cost curves for live storage.

Subsequently, the new Baghdara cost estimates became available from the project's prefeasibility study (Fichtner Consulting Engineers 2007). The extrapolated Kabul River Basin Master Plan unit costs for Baghdara[65] differ from the new prefeasibility study estimates by a factor of 4.1 (the recent estimate is over 4 times the extrapolated 1978 unit cost estimate). It should be noted that the capital cost of the new Baghdara project is only 5 percent greater than the extrapolated Kabul River Basin Master Plan estimate of capital cost, and this is principally because the dam is much smaller. This extraordinary difference may outline the broad range within which the real or actual present cost estimates lie, and it is not possible to say at this stage where the actual current cost estimates would fall in this broad range, unless more technical studies of the various options are carried out to an acceptable international standard.

Two important factors explain the change in Baghdara unit costs: the lowering of the maximum reservoir elevation from 1,460 meters above sea level to 1,420 meters above sea level; and shifting the dam axis to a downstream site. These changes, which reduced the maximum live storage of the project from approximately 860 million cubic meters to 220 million cubic meters, were made to the original site plan in the Kabul River Basin Master Plan to avoid large resettlement in the reservoir area. At a reservoir level of 1,460 meters above sea level, the consultants estimated that about 20,000 people would have to be resettled, and at 1,440 meters above sea level the estimated resettlement was less than 10,000. Regrettably, no analysis was made of different reservoir levels to estimate land acquisition requirements and the assets that would need to be replaced, the number of people affected, nor the resettlement, compensation, and restoration of livelihoods costs. Hence the cost to mitigate this impact for different reservoir levels and dam sites was not estimated. Instead, the maximum reservoir level of 1,420 meters above sea level was adopted to avoid resettlement wherein the resettlement cost, if smaller, is still significant. Several alternatives, based for example on reservoir levels 1,440 meters above sea level and 1,460 meters above sea level with their associated resettlement costs, should have been included among the alternatives evaluated.

For comparison, a hypothetical Baghdara project was formulated for this study with a reservoir level of 1,440 meters above sea level, assuming the same capital cost as the 1,420 meters above sea level project. The hypothetical project assumes that (a) there are 10,000 project-affected people; (b) the total land acquisition, resettlement, and compensation cost is approximately $20,000 per person; and (c) that at a reservoir level of 1,440 meters above sea level, the maximum live storage is 520 million cubic meters (an increase of 300 million cubic meters over a reservoir level of 1,420 meters above sea level).[66] The resulting project capital cost of $802 million is approximately 33 percent larger than the recent prefeasibility study estimate. The ratio of Baghdara hypothetical unit cost to extrapolated Kabul River Basin Master Plan costs is approximately 2.3.

Notwithstanding the lack of additional engineering studies and social assessments, three cost scenarios were formulated to reflect the range of costs discussed in the previous paragraphs:

a. Base Case scenario: using extrapolated Kabul River Basin Master Plan costs except at Baghdara, where the recent prefeasibility cost estimates were used.

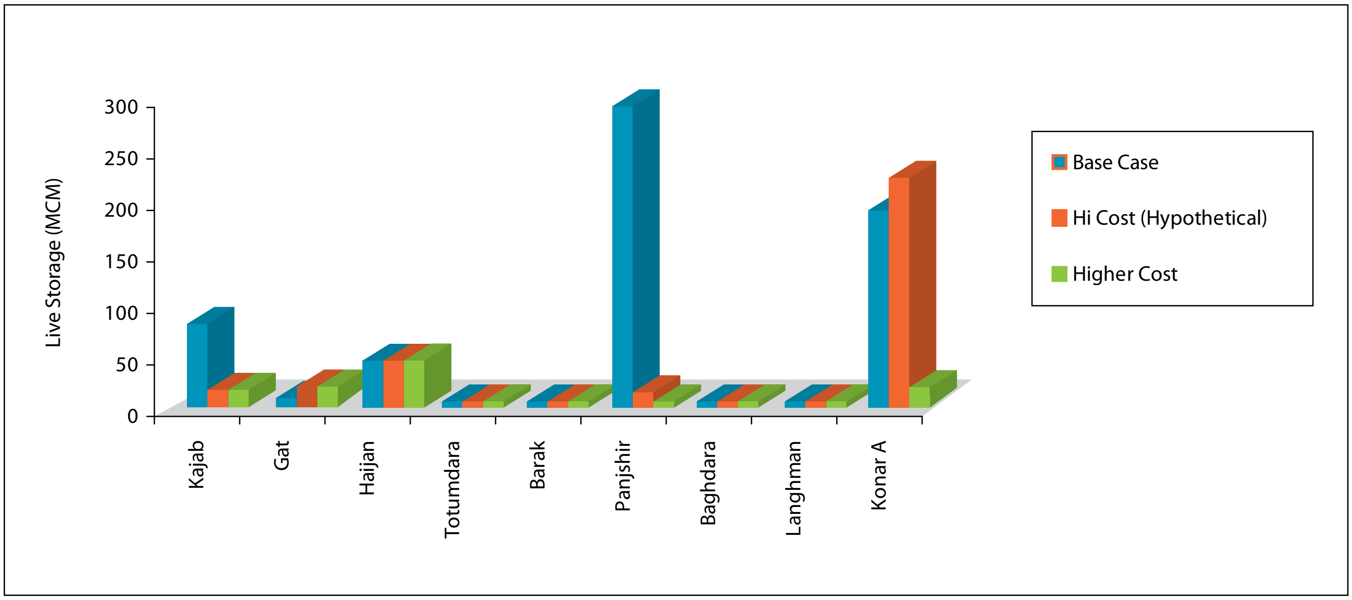
b. High-cost (hypothetical) scenario: Base Case, but using Baghdara hypothetical costs; all other storage and run-of-river option costs scaled up from the extrapolated Kabul River Basin Master Plan values by a factor of 2.3.

c. Higher-cost scenario: Base Case, but with Baghdara costs based on prefeasibility study estimates; all other storage and run-of-river option costs scaled up from the extrapolated Kabul River Basin Master Plan values by a factor of 4.1.

[65] The recent estimate of the capital cost of the Baghdara project is nearly the same as the extrapolated Kabul River Basin Master Plan estimate. However, the live storage of the proposed project is only about 25 percent of the Kabul River Basin Master Plan project. This substantial reduction was caused mainly by shifting the site of the dam and reducing the capacity of the reservoir to avoid resettlement costs, which were not estimated.

[66] The elevation-volume-area curves prepared during the prefeasibility study are not available. One reason may be that there is considerable uncertainty concerning the topography of the reservoir area. A large discrepancy was noted between existing topographic maps and GPS estimates made during the study – of as much as 50 meters.

**Figure E.9:** Change in Storage Options under the High Cost Scenarios




The results are highly sensitive to these costs and there is a substantial difference between optimal investment plans for each of these three scenarios. The storage options under each scenario are shown in figure E.9 Moving progressively from the Base Case to the high-cost (hypothetical) and on to the higher-cost scenario, the total storage drops dramatically in the Panjshir and Lower Kabul subbasins. Only about 15 percent of the storage developed under the Base Case is developed under the higher-cost scenario.

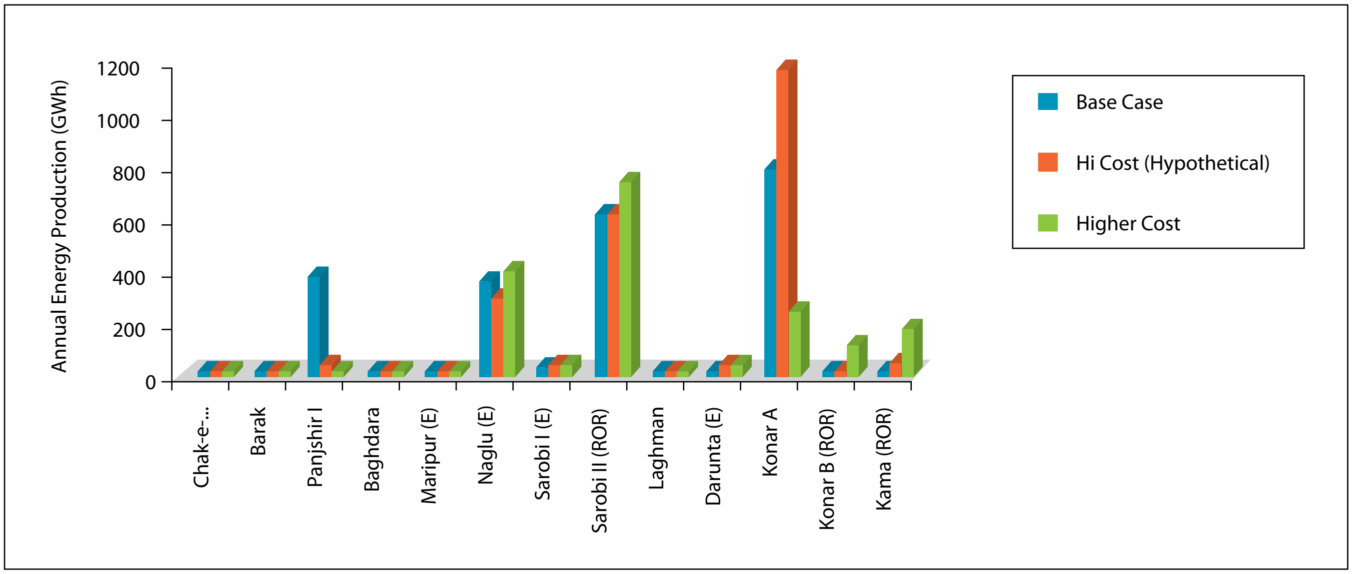
Energy production in high-cost scenarios shifts entirely to the Lower Kabul subbasin (figure E.10, consisting mainly of the run-of-river plants at Sarobi II, the two run-of-river sites on the Konar River, and, additionally, a small dam and reservoir upstream on the Konar River (Konar A). The irrigated area declines by approximately 21 percent, mainly in the Logar-Upper Kabul and Panjshir subbasins, because of the lack of storage.

Moving from the Base Case to the Hypothetical scenario (b); total irrigated area decreases by 19%. Total annual energy production is the same, but total net economic benefits decrease from 108 M$ per year to -16 M$ per year, and storage investment cost nearly doubles (173%). The change is even more dramatic in moving to Higher Cost scenario (c). Total annual energy production decreases 22%, net annual economic benefits are -226 M$ per year and storage costs are more than three times the cost of the Base case. The lesson in this brief experiment is clear: If realistic costs prove to be much higher than had been originally thought, the feasible economic potential of water resources development in the Kabul River Basin may be considerably below expectations.

Total net benefit is negative under both the High-cost (hypothetical) and Higher-cost scenarios, principally because though total storage declines from 613 million cubic meters to 105 million cubic meters, the storage and run-of-river option investment costs increase by a factor of 3.2 from $1.1 billion to $3.5 billion. However, under the High-cost (hypothetical) scenario, annual benefits and costs are nearly balanced (–$16 million), suggesting that the feasible cost range may lie between the Base Case and the High-cost (hypothetical) scenarios. The net economic benefit under the higher-cost scenario is –$237 million.

The availability of up-to-date cost estimates for storage infrastructure and run-of-river options is a major concern because of the strong sensitivity of optimization results to these data. If realistic current costs come out close to those in the hypothetical scenario, a viable plan that at least balances annual costs and benefits might be found. As costs rise, storage in the system declines, and the system will become less reliable given the degree of hydrological variability in the basin. In order to answer these questions about the overall economic feasibility of water resources development in the basin, updated planning (to at least

**Figure E.10:** Energy Production (GWh per year) under the High Cost Scenarios




prefeasibility level) is required for each of the key storage options (Kajab, Gat, Haijan, Panjshir I, and Konar) and the run-of-river options (Sarobi II, Konar B, and Kama).

## Base Case Alternative Sources of Bulk Water Supply for Kabul

As discussed in chapter 4, there are a number of different options for providing incremental domestic and industrial bulk water supply to Kabul. These include (a) surface and groundwater sources in the Logar-Upper Kabul subbasin where Kabul is located, and (b) surface and groundwater sources in the Panjshir subbasin located at some distance but directly north of Kabul. Several well fields in the Kabul valley supply water to Kabul, and when the present Short-Term Program to upgrade these sources and the Kabul water distribution system is completed, these sources will reach their ultimate capacity.[67] Choosing a combination of sources that satisfies projected bulk water production requirements and minimizes cost is a complex challenge as both subbasins[68] have other important water demands, including (a) existing and expanded irrigated agriculture, (b) energy production, (c) rural water supply, (d) water for the development of Aynak copper mine near Kabul, and (e) environmental flow requirements.

There are three important differences between groundwater and surface water sources for Kabul located in the Logar-Upper Kabul and Panjshir subbasins as represented in the DSS:

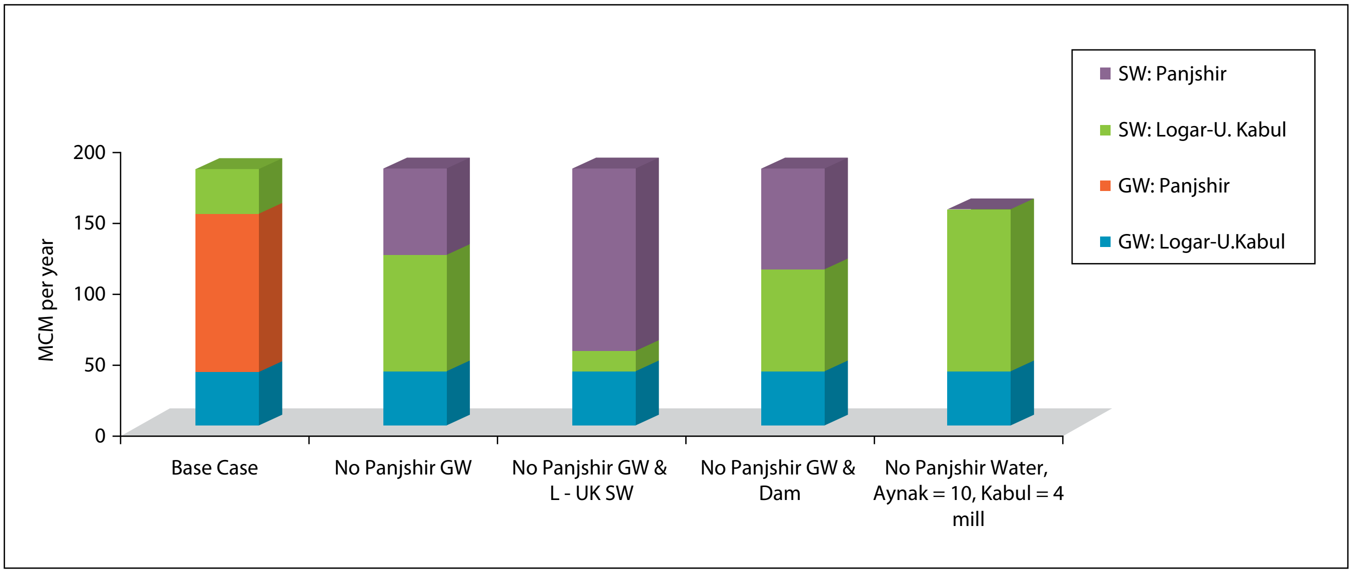
- Treatment costs for surface water are more than 3 times the treatment cost of groundwater.
- Groundwater from the Panjshir subbasin and surface water directly from the Panjshir River must be lifted about 400 meters to reach Kabul.
- Surface water from the Panjshir I dam at Gulbahar is assumed to utilize the head in the dam to offset about half of the total lift, reducing the pumping cost.

As noted in chapter 2, there are also important differences between the two subbasins as reliable sources of bulk

[67] There are no new groundwater sources in the Logar-Upper Kabul subbasin with the exception of possible increases in the capacity of the Logar aquifer from higher streamflows in the Logar River; however, this would reduce surface water supply from the Logar River with perhaps a saving in treatment costs. The largest existing source of Kabul water supply is a well field in the Logar River valley just east of the city and upstream of the confluence with the Upper Kabul River. This important aquifer is recharged by the Logar River streamflow. This recharge, equal to the present estimated capacity of this aquifer, is accounted for by the model in the water balance of the Logar. The hydrogeological studies carried out as a part of the Kabul feasibility study (Beller Consult, Kocks, and Stadtwerk Ettlingen 2004) suggested that this capacity might be increased if the lower Logar River streamflow could be regulated during critical low flow sequences. This is one important aspect of more detailed modeling and study of the Logar River basin, prior to detailed engineering of the recommended options.

[68] These multisectoral demands are also largely present in the Lower Kabul subbasin, and selecting alternative sources in the two upper subbasins is not independent of these demands in the lower subbasin.

**Figure E.11:** Base Case Alternative Kabul Water Supply Sources




urban and industrial water supply. The Logar and Upper Kabul subbasin is highly drought prone while the Panjshir subbasin has much higher and more reliable water resources because of the substantially greater winter snowfall in the high mountains of its watershed.

Figure E.11 compares the sources of incremental bulk domestic and industrial water supply for Kabul for five scenarios:

a. Base Case with 90 percent reliable streamflows, Kabul population of 4.74 million,[69] and high Aynak water requirements (43 million cubic meters per year). Each of the other scenarios is based on this scenario with changes as indicated.

b. Base Case with no Panjshir groundwater available.

c. Base Case with no Panjshir groundwater and no surface water available from the Logar-Upper Kabul subbasin except the Haijan dam on the Maidan River in the Upper Kabul, which also provides water for irrigation, rural water supply, and environmental flows through Kabul.

d. Base Case with no Panjshir groundwater and no water available from the Panjshir I (Gulbahar) dam but with a water conveyance link to the Panjshir subbasin.

e. Base Case with no water conveyance link to the Panjshir subbasin.

The results under each of these five scenarios are compared in figure E.11 in terms of the total surface water and total groundwater supplied from each subbasin, that is the Logar-Upper Kabul and Panjshir.

a. In the Base Case scenario, the primary source of incremental bulk supply is the groundwater aquifer in Parwan Province in the Panjshir subbasin, which provides approximately 61 percent of the incremental water production required. However, this groundwater source, located near Bagram in Parwan Province, is unproven hydrogeologically, though it is discussed at length in the Kabul water supply feasibility study (Beller Consult, Kocks, and Stadtwerk Ettlingen 2004). The effect of its development on the extensive development of irrigated agriculture in this area has not been determined.[70]

[69] Bulk water supply requirements are based on an average service rate of 85 liters per capita per day plus losses of 25 percent.

[70] The source of recharge for this extensive and relatively shallow aquifer is unknown. Rainfall is limited in the Shomali Plain and recharge from the Hindu Kush to the west and north would have to be proved. Hence in the model, it is assumed that the source of recharge is the rivers flowing in the Panjshir subbasin and this withdrawal of water is accounted for downstream of the confluence of the Ghorband and Panjshir rivers.

b. The result of eliminating the option of developing groundwater for Kabul in the Panjshir subbasin is to shift the sources of incremental bulk water supply to surface water from the Logar-Upper Kabul subbasin (78 percent) and to the Panjshir I dam (22 percent). Within the Logar-Upper Kabul subbasin, 87 percent of the incremental supply is surface water from the Logar River (97 million cubic meters per year). Total investment costs (figure E.12 rise about 12 percent but the average unit cost of incremental supply decreases by about 11 percent because of the decrease in water supplied from the Panjshir subbasin, which requires a substantial lift.

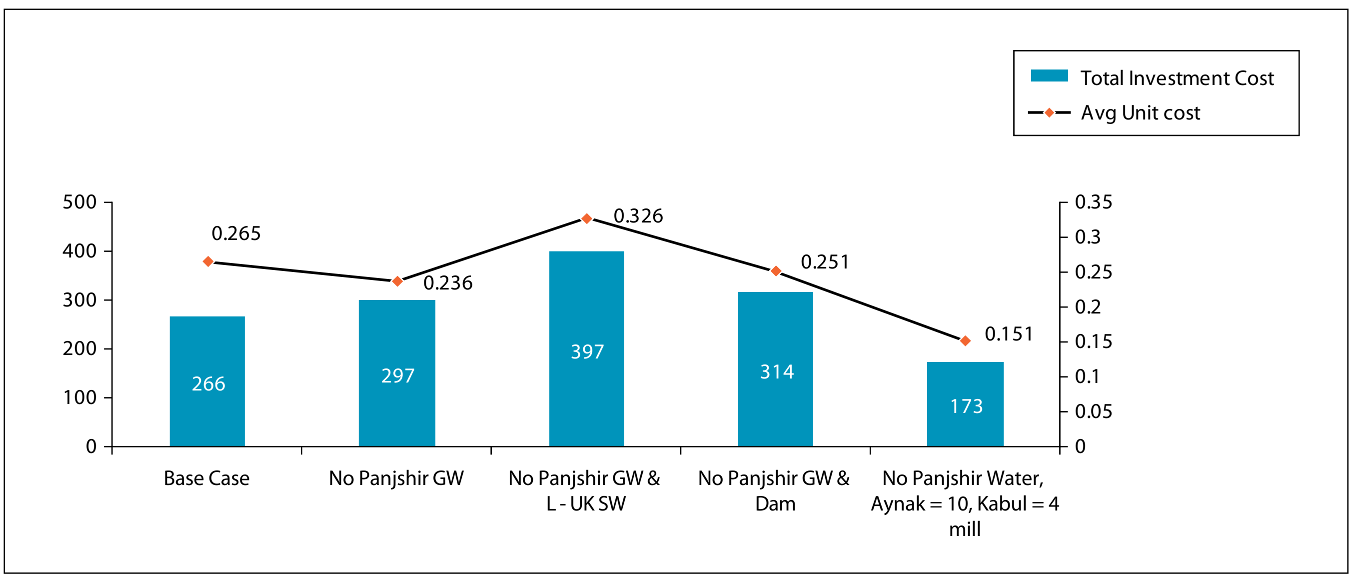
c. If both Panjshir groundwater and Logar River surface water are eliminated, 90 percent of the incremental bulk water supply is provided by the Panjshir I dam with the balance provided by the Haijan dam on the Upper Kabul River. This is the most expensive scenario, with a total investment cost (including the annual cost of pumping) of $397 million representing a nearly 50 percent increase over the Base Case; and an average unit cost of water of $0.33 per cubic meter being the highest among all scenarios.

d. If Panjshir groundwater and access to the Panjshir I dam are eliminated, the incremental bulk water supply is provided from two sources, namely surface water from the Logar-Upper Kabul subbasin (57 percent) of which 82 percent comes from the Logar River (67 million cubic meters per year), and 43 percent from the Panjshir River downstream of the confluence with the Ghorband River. Total investment cost for this scenario is $314 million, about 18 percent higher than the Base Case. However, the average unit cost of water is slightly below the Base Case (figure E.12).

e. In the last scenario, there is no link with the Panjshir subbasin and neither the projected 2020 Kabul population nor the Aynak mine can be fully supplied. The only feasible result with these constraints (shown in figure E.11) is to supply water for a Kabul population of 4 million (which is close to the current population), and provide less than a quarter of the full water requirement for the Aynak mine. Regardless which forecast for future Kabul population one accepts, a conveyance link with the Panjshir subbasin is essential. Hence, detailed studies of the water supply options in this subbasin are a high priority.

Dependence on the Logar-Upper Kabul subbasin varies substantially between the scenarios. However, it appears likely that in the short to medium term, the Logar River will play a major role in providing the incremental bulk domestic and industrial water supply for Kabul. This is because it will take some years to develop the infrastructure needed to

**Figure E.12:** Incremental Investment (US$ mil) and Average Unit Costs ($/m$^3$) of Incremental Kabul Water Supply



bring Panjshir subbasin water to Kabul, and in the short term the Logar River water will be needed for the Aynak copper mine. There are, however, several reasons to be cautious about a substantial long-term dependence on the Logar-Upper Kabul subbasin:

a. The Logar-Upper Kabul subbasin is the least reliable source of surface water in the Kabul River basin (see table 3.2).

b. The dams in the Logar-Upper Kabul subbasin, on which 22 to 86 percent of the incremental Kabul bulk water supply will depend (depending on which alternative set of options is ultimately chosen), are likely to involve high and as yet unknown resettlement and compensation cost, which may significantly increase their total development cost.

c. It has been assumed that the water supply for Aynak is drawn from the Logar River at a point upstream of the proposed Gat reservoir, and that all return flows are routed to a point downstream of where the Logar and Upper Kabul rivers join. The possibility of recycling substantial portions of water used in ore processing has not been investigated, nor have the potential water quality impacts of the mine and its associated settlement (of approximately 25,000–30,000 people) been considered. While this is the reason for assuming that return flows would be routed around the lower Logar River, measures may nevertheless be needed to protect the groundwater in the Logar River valley.

d. Irrigation development in the Logar-Upper Kabul subbasin under these scenarios ranges from 21,305 hectares to a low of 14,971 hectares under the scenario in which there is no link with the Panjshir subbasin. The maximum level of irrigation development is about 67 percent of the maximum potential of 31,660 hectares (Montreal Engineering Company 1978).[71] There are no recent data on the actual level of current irrigation (perennial or intermittent) and the volume of current water use, nor is there an updated estimate of potential development. However, many of these scenarios may cause a significant shift in water allocation from irrigated agriculture to urban water supply, and to mining and ore processing. Such a shift would be highly problematic without agreement on changes in customary water rights and compensation of existing users who must give up their present water rights.

While there clearly seems to be an essential requirement for a link to the Panjshir subbasin, the range of source options in the subbasin and the importance of the Logar-Upper Kabul subbasin, at least in the short to medium term, suggest that several important studies are needed before this part of the Kabul River basin development and investment plan can be finalized. These are:

a. Detailed hydrogeological exploration and investigation of potential sources of groundwater in Parwan Province. This includes identifying sources and rates of recharge, sustainable yield, relation to irrigated agriculture in the Shomali Plain, and streamflow in the Panjshir River under different development scenarios, with costs of extraction and conveyance to Kabul at different levels of development.

b. Preliminary engineering studies of alternative surface water sources in the Panjshir subbasin, including headworks and conveyance costs at different levels of development.

c. Preliminary engineering studies of treatment modalities and costs at different levels of development of surface water from both the Logar-Upper Kabul and Panjshir subbasins and for groundwater from Parwan Province.

d. Comprehensive updating of the knowledge base of the Logar-Upper Kabul subbasin to include (a) present land and water use; (b) storage potential and costs, including resettlement, upgraded hydrological monitoring, measurement of existing water diversions, and estimates of irrigation return flows; and (c) a comprehensive integrated plan for the subbasin in the analytical context of the overall Kabul River basin development and investment plan.

[71] This total excludes the substantial area of over 37,000 hectares to the north of Kabul and the Upper Kabul River that can only be served by treated wastewater and stormwater flows from Kabul. Assuming 40 percent sewer coverage by 2020 and ignoring stormwater flows, the area irrigated under the various scenarios in this study is generally less than 2,000 hectares. If the winter flows from Kabul could be stored, another 4000–5,000 hectares could be developed in this area.

## High Kabul Bulk Water Supply Demand Scenarios

The estimates of the current Kabul population and its future projections are both highly uncertain, as the city is continuing to expand in all directions without adequate planning. The population forecasts for Kabul range from the levels assumed in this study at about 4.74 million people in 2020 to approximately 8 million in the near future, which is also modeled in one of the scenarios. There is a possibility that such high population levels could materialize in Kabul, due to persistent rural poverty and lack of economic opportunity in the smaller regional towns and centers.

It is strategically important to examine these possibilities in the context of the long-term development and investment plan for the Kabul River basin. The questions, therefore, are whether such high levels of Kabul's water supply demand can be accommodated, whether it would be necessary to change the short- to medium-term options for Kabul's water supply, and how it would impact the overall Kabul River basin water resources development plan.

The results from a series of scenarios for high Kabul water supply demand are shown in figure E.13 in terms of the total surface and groundwater supplied from each subbasin. The series of scenarios include:

a. Base Case (table 6.1) with Kabul population of 4.74 million: water demand 187 million cubic meters per year, including losses of 25 percent.

b. High Kabul with population of 6 million: water demand 232 million cubic meters per year.

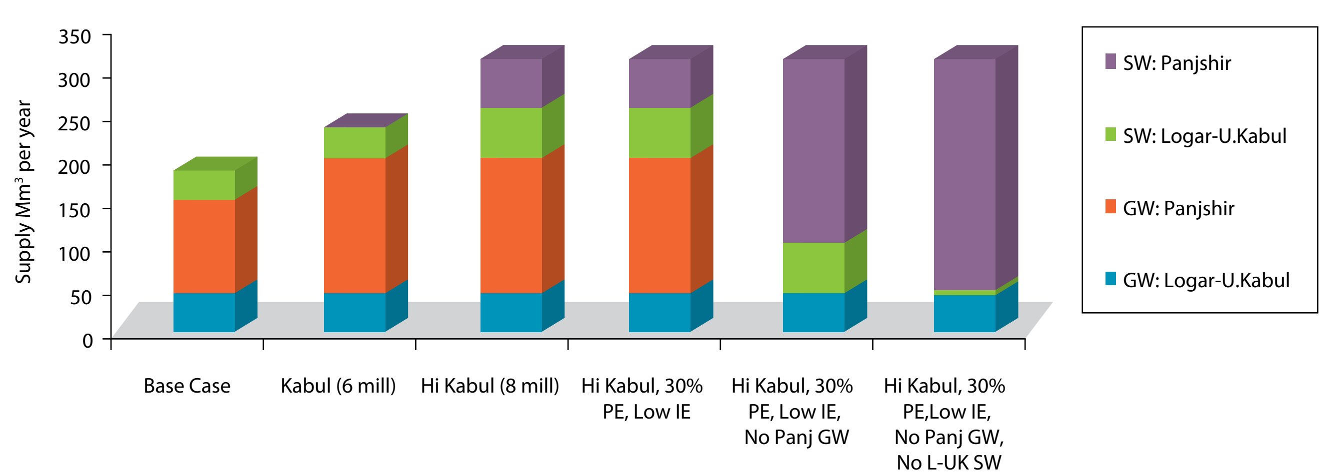
c. High Kabul with population of 8 million: water demand 309 million cubic meters per year.

d. High Kabul with population of 8 million, plus 30 percent power exports from Kabul River basin, low irrigation efficiency (35 percent), and no Panjshir subbasin groundwater.

e. High Kabul with population of 8 million, plus 30 percent power exports from Kabul River basin, low irrigation efficiency (35 percent), no Panjshir subbasin groundwater, and no surface water from the Logar-Upper Kabul subbasin.

In the first three scenarios, in which the only change is an increase in the projected Kabul population from 4.74 million in 2020 to 8 million in 2020, Kabul's total water demand rises from approximately 187 million cubic meters to 310 million cubic meters per year. Groundwater development in the Panjshir subbasin expands to meet the increased demand (figure E.14). However, as

**Figure E.13:** Sources of Kabul Water Supply with High Kabul Population Scenarios

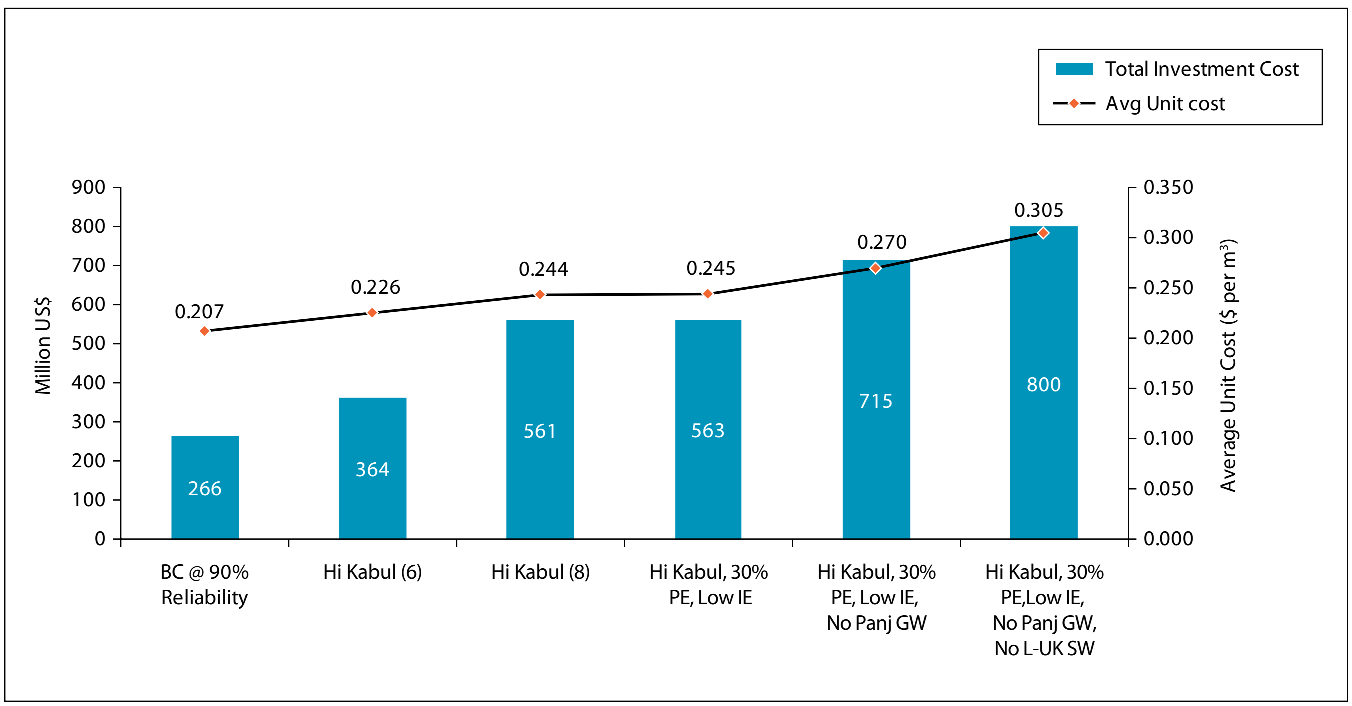


the assumed sustainable yield limits are approached (158 million cubic meters), surface water from the Logar and the Panjshir is tapped to satisfy the increased demand. Irrigation decreases by approximately 9 percent in the Logar-Upper Kabul subbasin. The storage options remain the same as the Base Case, but developed storage declines by approximately 15 percent in the Logar-Upper Kabul subbasin. Total investment cost rises by approximately 111 percent to approximately $561 million and the average unit cost rises by approximately 6 percent to approximately $0.28 per cubic meter (figure E.14).

The fourth scenario combines a high Kabul population (8 million) with 30 percent power exports from Kabul River basin and low irrigation efficiency. The intention is to test the options for meeting this high level of Kabul bulk water demand when overall water demand increases and the basin infrastructure system is stressed to meet all demands. There is no change in the options to satisfy high Kabul water demand and practically no change in the investment and average unit cost of Kabul water supply, but irrigation declines a total of 18 percent in the Logar-Upper Kabul subbasin and about 3 percent in the Panjshir subbasin. As a result of increased energy demand, the storage at Panjshir I (Gulbahar) increases by approximately 51 percent.

In the final two scenarios, the key options are dropped while keeping Kabul and overall water demands high. First, Panjshir groundwater is dropped as an option. In this case, the supply from the Logar-Upper Kabul remains unchanged and the balance of demand is met from the Panjshir I (Gulbahar) reservoir. The irrigated area remains the same in the Logar-Upper Kabul subbasin, but declines 9 percent in the Panjshir subbasin. Storage at Panjshir I increases slightly by 4 percent. In the second case, Panjshir groundwater and surface water from the Logar-Upper Kabul are both dropped. All incremental Kabul water demand is met from the Panjshir I reservoir; irrigated area in the three subbasins remains the same; and Panjshir I reservoir storage remains practically the same. Maximum energy demand is generated and met in these two scenarios. In all of the high Kabul demand scenarios, the total energy generated in the Lower Kabul subbasin ranges from 68 percent to 73 percent of maximum annual energy demand. The cost of Kabul water supply increases substantially in these two scenarios. Investment costs increase 27 percent and 43 percent over the unconstrained scenario with a Kabul population of 8 million. Under the scenario without Panjshir groundwater and Logar-Upper Kabul surface water, the investment cost is 3 times that of the Base Case. Average unit cost of water increases similarly,

**Figure E.14:** Investment Cost and Average Unit Cost of Kabul Bulk Water Supply with the High Kabul Population Scenarios



from $0.28 per cubic meter to a maximum of $0.35 per cubic meter.

The conclusions from this preliminary analysis are:

a. The high water demand associated with a Kabul population of 8 million can be accommodated in several ways, both with and without Panjshir groundwater and surface water from the Logar-Upper Kabul subbasin.

b. However, the cost of the overall basin development and investment plan increases by 32 to 41 percent to accommodate both high Kabul bulk water demand and water demand in other sectors.

c. A link with the Panjshir subbasin is vital in both the Base Case and high Kabul demand scenarios. However, there is presently high uncertainty concerning the cost and feasibility of each option. A further engineering study of the Kabul water supply options at alternative development levels is imperative to determine their feasibility, limits, and costs.

d. The Panjshir I dam plays a pivotal role in accommodating both high Kabul water supply demand and high irrigation and energy demand. Assuming that the relative costs of storage and run-of-river options remains the same as in the Base Case, the feasibility of staging the development of Panjshir I should be investigated. This would give the overall investment plan the flexibility to adapt to different patterns of increased water demand.

If a conveyance link to the Panjshir subbasin[72] can be assumed, a projected Kabul population up to 8 million at a water production rate of 85 liters per capita per day, along with the full Aynak mine water requirement of 43 million cubic meters, can be met. Table E.2 shows the results for five simple scenarios each based on the Base Case (table 6.1 with Naglu at 100 megawatts capacity), except as indicated for Kabul population and the availability of Parwan groundwater. All these

**Table E.2 Kabul Bulk Water Supply: Strategic Options with a Conveyance Link to the Panjshir Subbasin**

| | | Base Case | | | | |
|---|---|---|---|---|---|---|
| **Kabul population** | Million | 4.74 | 6 | 6 | 8 | 8 |
| **Parwan groundwater** | Yes/No | Yes | Yes | No | Yes | No |
| **Basin investment plan** | | | | | | |
| Gross annual economic benefits | Million $/yr | 362.5 | 362.5 | 352.8 | 359.1 | 353.8 |
| Investment cost | Million $ | 2,453.4 | 2,548.3 | 2,571.9 | 2,718.7 | 2,824.2 |
| Net annual economic benefits | Million $/yr | 109.5 | 103.6 | 98.0 | 92.1 | 85.3 |
| **Cost of incremental Kabul BWS** | | | | | | |
| Annual cost | Million $/yr | 37.9 | 52.2 | 51.1 | 75.2 | 78.5 |
| Investment cost | Million $ | 266.2 | 364.4 | 443.5 | 561.1 | 675.9 |
| Average unit cost | $/m³ | 0.265 | 0.272 | 0.266 | 0.280 | 0.291 |
| **Incremental Kabul BWS sources** | | | | | | |
| Existing sources | MCM/yr | 39.6 | 39.6 | 39.6 | 39.6 | 39.6 |
| SW: Upper Kabul River | MCM/yr | 14.8 | 14.9 | 14.7 | 14.7 | 14.7 |
| SW: Logar River | MCM/yr | 17.3 | 20.5 | 67.1 | 42.0 | 67.2 |
| SW: Panjshir River | MCM/yr | 0.0 | 1.1 | 110.1 | 55.0 | 187.9 |
| GW: Parwan | MCM/yr | 111.0 | 155.3 | 0.0 | 157.2 | 0.0 |
| **Multipurpose storage** | | | | | | |
| Logar River (Kajab & Gat) | MCM | 84.7 | 80.9 | 61.9 | 61.9 | 66.4 |

72 This assumes that multiple surface and groundwater sources are consolidated in a single pumping-conveyance system to bring the water to Kabul.

| Table E.2 Kabul Bulk Water Supply: Strategic Options with a Conveyance Link to the Panjshir Subbasin | | | | | | |
|---|---|---|---|---|---|---|
| | Base Case | | | | | |
| Upper Kabul River (Haijan) | MCM | 43.2 | 43.2 | 43.2 | 43.2 | 43.2 |
| Panjshir River (Panjshir I) | MCM | 292.4 | 292.4 | 292.4 | 292.4 | 292.4 |
| **Cost of multipurpose storage** | | | | | | |
| Logar River (Kajab & Gat) | Million $ | 67.8 | 64.9 | 35.2 | 48.0 | 46.2 |
| Upper Kabul River (Haijan) | Million $ | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 |
| Panjshir River (Panjshir I) | Million $ | 387.3 | 387.3 | 387.3 | 387.3 | 387.3 |
| **Irrigated area: Logar-Upper Kabul** | | | | | | |
| Logar River | ha | 14,009 | 13,652 | 8,090 | 11,120 | 8,090 |
| Upper Kabul River | ha | 5,750 | 5,750 | 5,750 | 5,750 | 5,750 |

*Note: BWS = bulk water supply; SW = surface water; GW = groundwater.*

scenarios assume a conveyance link with the Panjshir subbasin.

From a strategic perspective, looking beyond the original 2020 Kabul population projection of 4.74 million (section 3.3), the scenario in table E.2, based on a population of 6 million and no Panjshir groundwater, would be an optimal *medium-term* choice, as it has the lowest unit cost of bulk water supply. This plan is flexible and, if the population increases beyond 6 million to 8 million, this plan can be expanded to meet these increased bulk water supply needs by increasing the allocation of water from the Panjshir River at the Panjshir I dam. This Kabul Medium-Term Plan scenario is further discussed below in the context of other sectors in the Kabul River basin.

## Energy Production Options with and without Exports

Five existing hydropower stations in the Kabul River basin are included in the model and they generate between 410 and 448 gigawatt-hours, depending on the demand and hydrological scenario. The largest and most important of these is the Naglu dam and reservoir (live storage of 379 million cubic meters and installed capacity of 75 megawatts[73]), located downstream of the confluence of the Panjshir and Upper Kabul rivers. In addition, as discussed in chapter 4, the Kabul River basin has substantial hydroelectric power generation reserves.

This section examines the pattern of generation among the proposed options, including the largest existing facility at Naglu, under two demand scenarios:

a. Minimum and maximum annual electricity demand as in the Base Case (table 6.1 and table 4.2);

b. Additional power export demand of 30 percent of the Base Case minimum and maximum annual electricity demand (section 4.3).

The overall pattern of generation under four scenarios in which both demand and supply options vary is shown in figure E.15. The scenarios focus on the presence or absence of the most important options in the Lower Kabul River basin (Sarobi II and Konar A), mainly because of the current security and site access issues that make these options not practical for consideration in the short term.[74] The scenarios include:

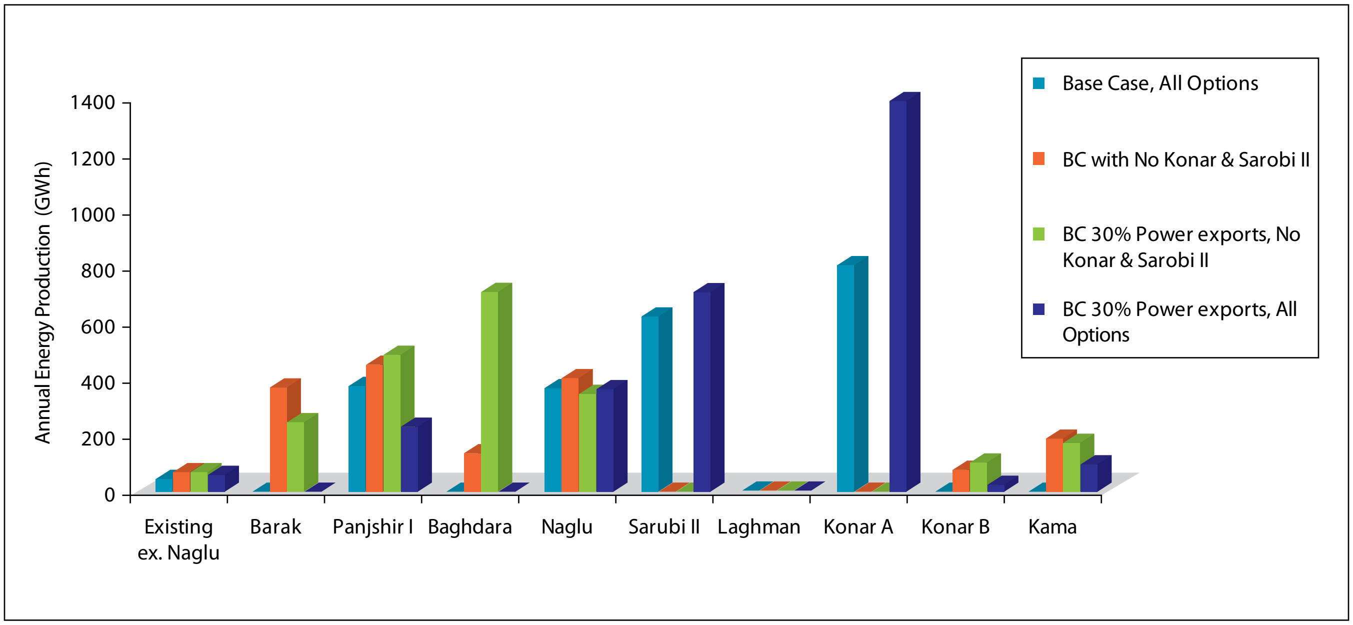
a. Base Case (table 6.1) with 90 percent streamflow reliability;

b. Base Case without the two major hydropower options in the Lower Kabul River basin – Konar (storage) and Sarobi II (run-of-river);

[73] The addition of a fourth 25-megawatt unit is ongoing.

[74] Sarobi II and Konar A always appear as important components of the hydropower generation system in the basin, when they are assumed to be available. Strategically, in the long run, these options will be of great importance to Afghanistan. The scenario without Panjshir I and with Sarobi II and Konar is not shown because, when Panjshir I is dropped, all the generation shifts to Sarobi II and Konar with ease but the lack of storage in the Panjshir subbasin results in a decrease in irrigated area and the elimination of a critical strategic source of water supply for Kabul.

**Figure E.15:** Energy Generation Options




c. Base Case with 30 percent power exports, and without Konar and Sarobi II;

d. Base Case with 30 percent power exports and all options available.

Under the Base Case scenario without Konar (storage) and Sarobi II (run-of-river), generation is concentrated in the Panjshir subbasin, at the existing dam at Naglu (where the Panjshir and Upper Kabul rivers join), and at two run-of-river sites on the lower Konar River (Konar B and Kama). When energy demand is increased by 30 percent, and Konar and Sarobi II are again dropped, the resulting generation pattern is the same. These are the only two scenarios in which Barak (a storage reservoir upstream of Panjshir I) and Baghdara (a storage reservoir downstream of Panjshir I) appear in the result.

Under the Base Case with 30 percent power exports and all options available, Barak and Baghdara drop out; the storage reservoir at Panjshir I continues to provide substantial energy; but the greater part of the load is shifted to the run-of-river site at Sarobi II and the storage site on the Konar River (Konar A) with a small amount of generation at the farthest downstream run-of-river site on the Konar River. The Konar run-of-river hydropower options are only selected when demand is increased or the Konar River storage option is not available.[75]

The pattern of annual generation for the whole system, annual energy demand, and total net economic benefit for the basin investment plan is shown in figure E.16 for the same set of scenarios. Only in scenarios with all options available does the system generate the hydropower to meet the maximum demand. The annual net economic benefit for scenarios with all options available is roughly 6 times greater than the annual net economic benefit under scenarios without Konar and Sarobi II. Net economic benefit is negative for the Base Case without Konar and Sarobi II, and slightly positive for the same scenario with exports and increased demand. The irrigated area remains the same under each of the four scenarios as does the sources of water supply for Kabul. The principal reason for the large difference in net benefit among the scenarios is that in scenarios without Konar and Sarobi II, the system includes some of the most costly options available in order to satisfy minimum energy demand.

[75] The largest generation at these two options occurs when the Konar River storage option is not available, and the lower option at Kama is consistently preferred. This suggests that if security and access issues prevent the Konar River storage option from being considered for a considerable time in the future, then Kama, the farthest downstream site on the Konar River, should be given high short-term priority. However, as the Konar River valley widens as it approaches the Kabul River, and is intensively cultivated, even a low-head, run-of-river option at this site may involve substantial resettlement.

**Figure E.16:** Total Energy Generated and Annual Total Net Economic Benefits

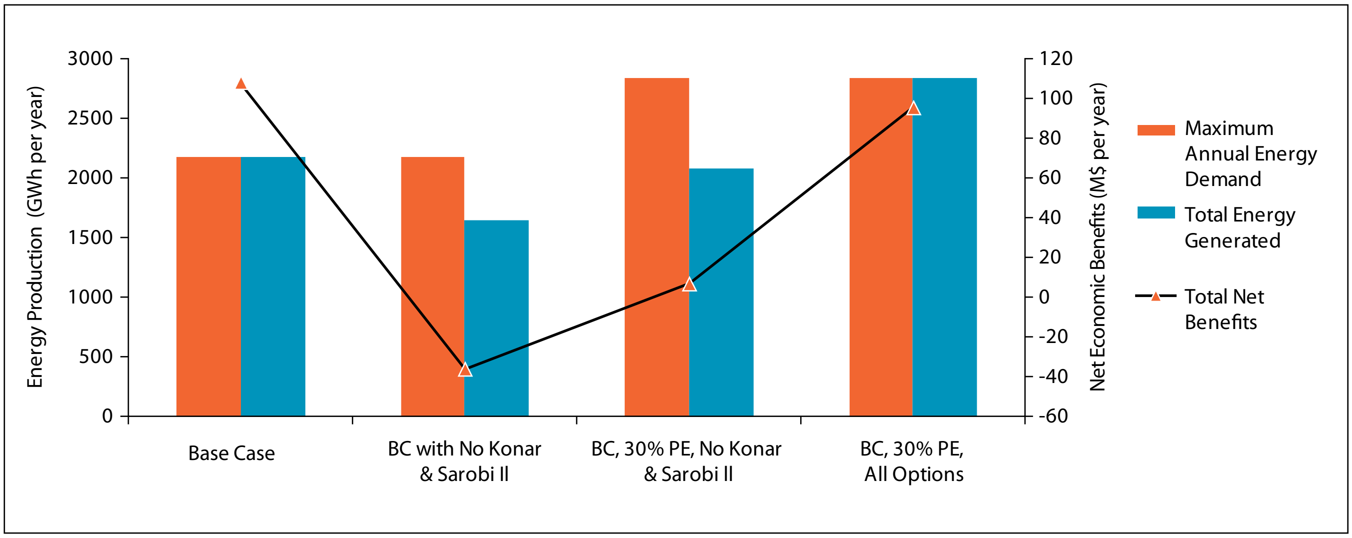
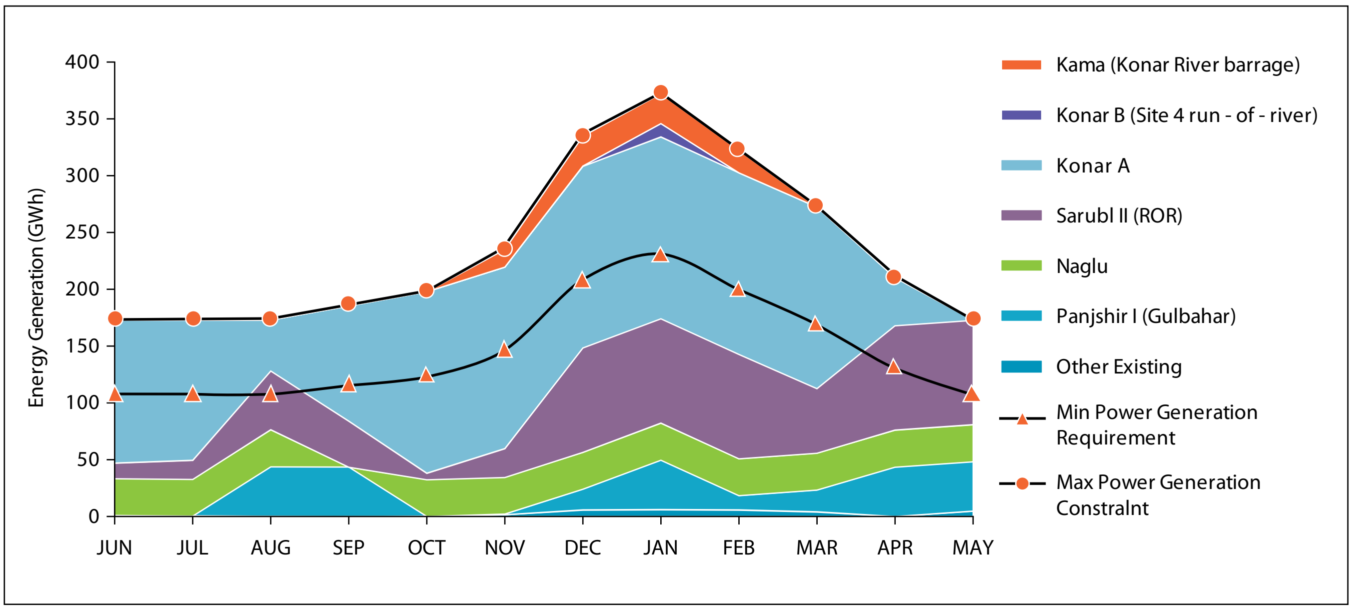


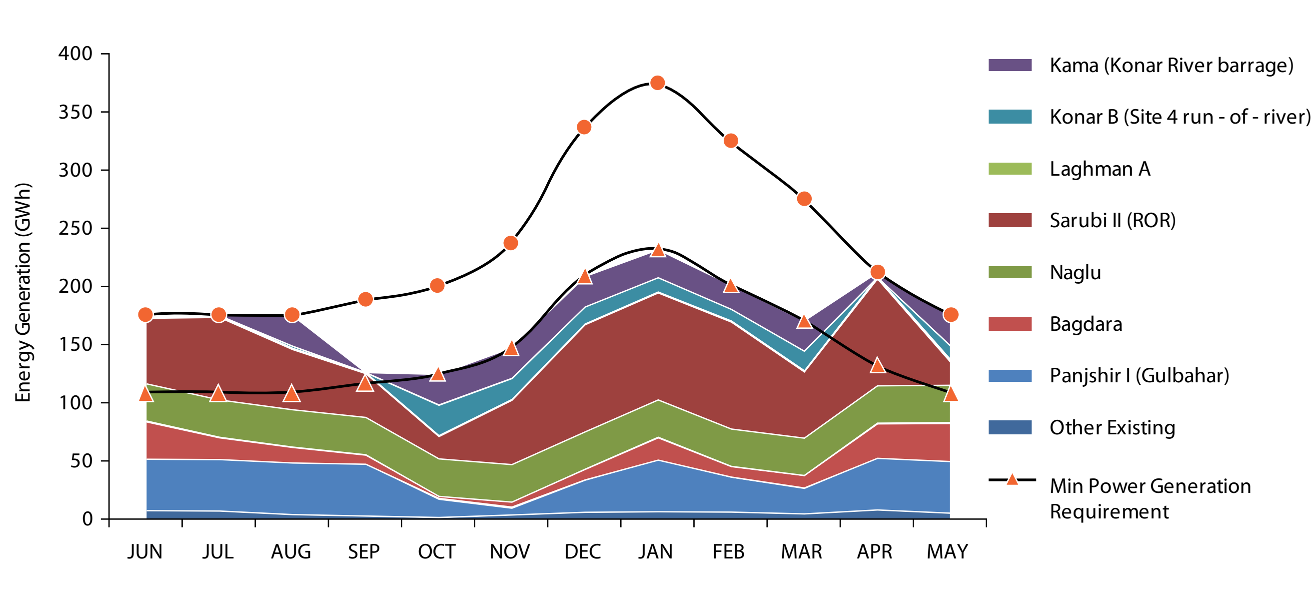

**Figure E.17:** Base Case Energy Generation: 30% Energy Exports; All Options




Figures E.17and E.18 show the pattern of monthly energy generation at each dam in the basin hydropower system for the Base Case scenario with 30 percent power exports under two different assumptions: first, with all options available (figure E.17); and second, without the Konar A (storage) option (figure E.18).

a. The monthly pattern in the scenario with all options available (scenario d) is similar to the pattern in figure E.4 in which there are no exports. Dispite the large increase in energy demand, irrigation development in the Panjshir subbasin is at the maximum, and all incremental bulk water supply for Kabul is provided by Panjshir groundwater. This aquifer is assumed to be recharged from the Panjshir and Ghorband rivers, so this transfer of water to Kabul is accounted for as a withdrawal from the Panjshir River below its confluence with the Ghorband River. The critical option in the basin hydropower generation system is Konar A.

**Figure E.18:** Base Case Energy Generation: 30% Energy Exports; No Konar A




b. June to Novermber is a critical period for the cascade from Panjshir I to Naglu to Sarobi II: there is no generation in at least one of these plants during each month of the period; and in general the total production or output of the combined cascade averages about half of that during the period December to May. The generation at Konar expands during these months to overcome the deficit.

c. The importance of Konar A is underscored by the scenario shown in figure E.18 in which exports are 30% but the Konar A option is not available. The pattern of energy production changes significantly. First, overall energy production does not exceed the minimum level of annual demand (increased by the export demand) except during April to September. Second, approximately one third of the bulk water supply for Kabul is shifted to the Logar-Upper Kabul subbasin; irrigated area declines approximately 14 percent in the Logar River basin, but irrigation development remains at the maximum level in the Panjshir subbasin. Energy production at Panjshir again is reduced to zero in November. Baghdara is a part of the system in this scenario. The economics of the basin plan also changes significantly, with total basin plan investment cost increasing by approximately 13 percent from $2.89 billion to $3.25 billion, and net economic benefit falling from $95 million per year when all options are available to – $1.7 million per year without Konar A.

Under a wide range of scenarios, the August to November period is critical for energy production in the Panjshir-Naglu-Sarobi II cascade in the middle and upper Kabul River basin. This is strongly influenced not only by the choice of bulk water supply options for Kabul and by water demand for agriculture, which is maximum in the months of June through September, but also by the need to provide winter energy.

A second important and strategic observation is that the Konar storage project is a critical component of the Kabul River basin hydropower system. This option is important for meeting higher levels of demand, especially in the winter peak demand season, and for compensating for shortfalls in generation elsewhere in the system due to low streamflows or increased demand in other sectors. Not only does the Konar A option control the largest and most reliable source of streamflow in the Kabul River basin[76] and comprise the

[76] Should planning progress on this option? Pakistan's plan to construct a substantial storage and hydropower project, involving a reservoir with live storage of about 715 million cubic meters and 150 megawatts of installed capacity, upstream on the Konar River would need to be considered.

largest volume of live storage[77] and installed generation capacity, it also does not have to satisfy sector demands other than energy. One exception to this in the future might be the requirement to maintain a prescribed monthly flow in the Lower Kabul River as it passes into Pakistan.

## Alternative Energy Demand Scenarios

As discussed in chapter 3 and in the preceding section, relying on hydropower alone to meet the projected annual Kabul River basin energy demand, with or without the additional export demand, is problematic because of the differences in the timing of peak water demand in different sectors. This results in low generation capability in the August to November period and stresses reservoir operations, especially when streamflows are low.

The hydropower production system for the Kabul River basin, outlined in the previous section, can cope with the maximum annual demand curve (section 4.3) enhanced by 30 percent exports as long as the Konar A storage option is a part of the system (figure E.17). However, at least three considerations suggest that planning of the Kabul hydropower system, at least for the middle term, should be based on a different and perhaps more realistic demand curve. First, even though there is substantial unmet electricity demand at present in the basin, demand growth will for some time be constrained by the process of upgrading and expanding the transmission and distribution system.[78] Second, hydropower infrastructure has a long gestation period (much longer than for thermal generating sources), and involves detailed planning, feasibility and design, financing, and construction that can extend to 8–12 years or longer depending on the scale, complexity, and site access of the project. Third, it may be important not only from an operating and reliability perspective but also an economic and financial perspective to broaden the mix of electricity sources to include thermal (from gas and coal) to meet winter peak power and energy demand, to import electricity, and to continue to expand the deployment of other renewables such as solar and wind.

Two alternative energy demand scenarios have been formulated using the load duration curve (the upper curve in figure E.19 in place of the original demand curve that is shown in section 4.3). These scenarios assume that substantial thermal power is added to the overall electricity supply system to be dispatched primarily in the winter peak demand season. As the seasonal demand pattern in Central Asia from where imported electricity would most likely originate is similar to that in Afghanistan, it is assumed that this imported electricity will be available primarily in the summer season, that is, from May to September. Hence, in these two alternative scenarios, the basin hydropower system is planned primarily to provide baseload energy.

The two scenarios are depicted in figure E.19, which shows the monthly load duration curve for energy demand, along with the assumed contributions of thermal power, hydropower, and imported electricity. Energy values are assumed to be constant throughout the year.

a. In Alternative A, the basin hydropower system would provide half the winter peak month energy demand (amounting to 7 percent of annual energy demand) and provide that constant percentage of annual demand each month until demand drops below that level. Thermal sources would be confined to providing energy during the winter peak demand season from November to March.

b. In Alternative B, the basin hydropower system would provide approximately one third of the winter peak month energy demand (amounting to 5 percent of annual energy demand) from December to February. From March to November, the basin hydropower system would provide baseload energy of about 4 percent of annual energy demand. Thermal sources would provide the balance of demand in the winter season from September to April, and imported electricity would supplement the basin hydropower in the summer season (May through August or September).

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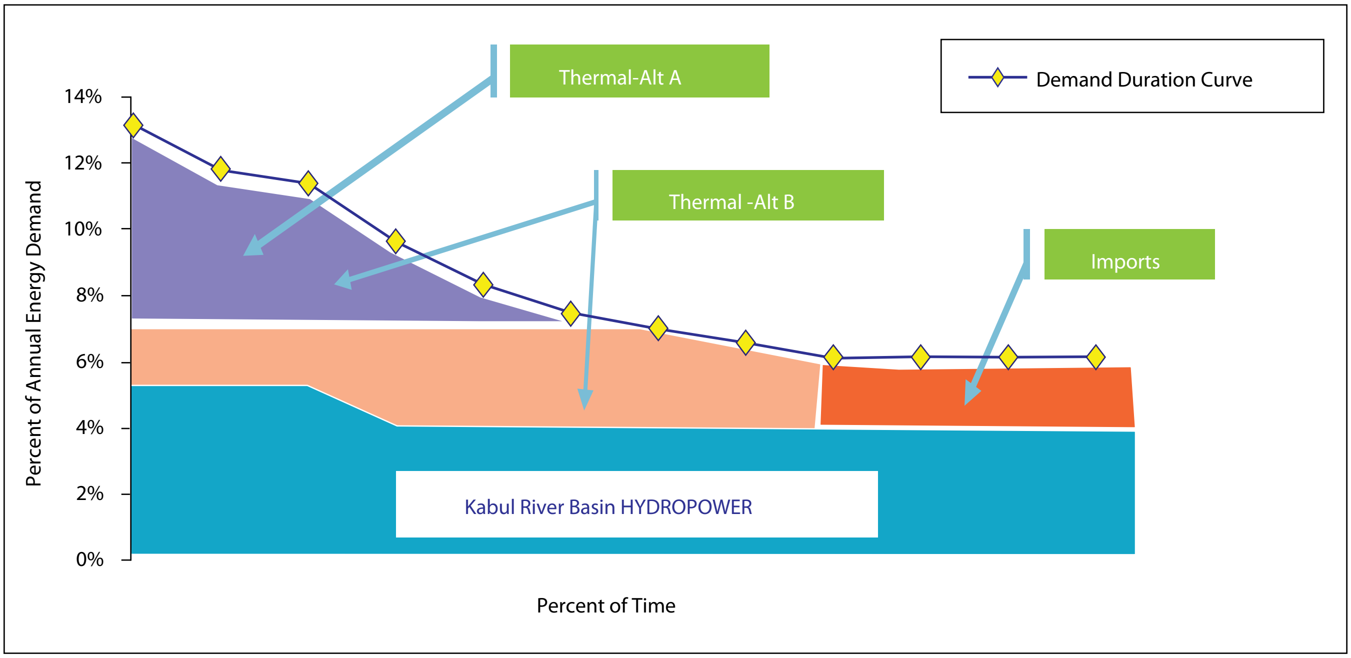
77 In the Base Case without power exports, the live storage developed at Konar A is 174 million cubic meters, and in the scenarios with 30 percent power exports it is 261million cubic meters. The latter volume of live storage is the largest utilized under any of the scenarios discussed in this appendix. However, this is just 26 percent of the maximum volume of storage that could be developed at the site. Hence, taking into account the potential future need to regulate the flow of the Kabul River as it crosses into Pakistan, the potential for this option to generate considerably more power and energy, possibly for export to Pakistan as well as elsewhere in Afghanistan, would need to be considered. This also suggests that it may be attractive to design the project to be staged as demand and other commitments increase in the future.

78 However, as this is at present a high-priority investment of the government, and has attracted substantial donor support and financing, the long gestation period for adding hydropower capacity may still ultimately be the constraint.

**Figure E.19:** Alternative Kabul River Basin Hydropower Demand Curves in a Mixed Hydro-Thermal-Impory System




The position of the imported electricity in the load curve depends on its availability. High electricity demand occurs in winter in both central asia and Afghanistan and June through September are the peak months for agricultural water demand in Central Asia and Afghanistan. Hence in both cases it is difficult for dam operators to store water for winter release and electricity generation in the summer months. Hence it is most likely that imported electricity will be in summer and this is not be very advantageous to the operation and production of the Kabul River basin hydropower system.

In Alternative A, thermal sources provide approximately 20 percent of the annual energy demand, with the remaining 80 percent being provided by the basin hydropower system but with a peak load of approximately half that in the original demand curve (figure 4.1 and table 4.3). The result for this scenario, based on the Base Case scenario without Konar A but with Naglu at full capacity of 100 megawatts, is shown in figure E.20. The primary capacity of the basin hydropower system in this scenario is located at Panjshir I, Naglu, and Sarobi II (run-of-river). All Base Case water demands are fully satisfied, irrigation development is not reduced from the maximum under the Base Case, and the system has little trouble meeting electricity demand. The other demands are fully met and e.

If the Sarobi II option is dropped (figure E.21), the basin hydropower system generates the *minimum* energy requirement in the winter season from September to April, but overall about 93 percent of the maximum annual energy demand. It should be noted that Baghdara is introduced to utilize the outflow from Panjshir I and increase generating capacity between Panjshir I and Naglu. Total storage in the system increases by about 18% and total basin plan investment cost increases by $493 million (21 percent), and net economic benefit decreases by $78 million per year (58 percent).

In Alternative B, the thermal power system would provide 49 percent of annual energy demand and nearly two thirds (64 percent) of energy demand in the winter peak month of January (figure E.19). Reliable imports of electricity are assumed to be limited to the months of May through September. Hence, in this alternative demand scenario, the basin hydropower system provides primarily baseload energy to the electricity grid. The results of applying this demand scenario are shown in figure E.23, without Konar A and Sarobi II, and with Naglu at full capacity (100 megawatts). The system performs well except in the winter months (December through January) when it is unable to produce the maximum power demand.

The results change significantly if Sarobi II is added to the system for the scenario depicted in figure E.23. Energy generation shifts to Naglu and Sarobi II (only a very small about of energy is generated at Panjshir I) and total energy

**Figure E.20:** Base Case with Energy Demand Alternative A: Without Konar A & Naglu=100MW

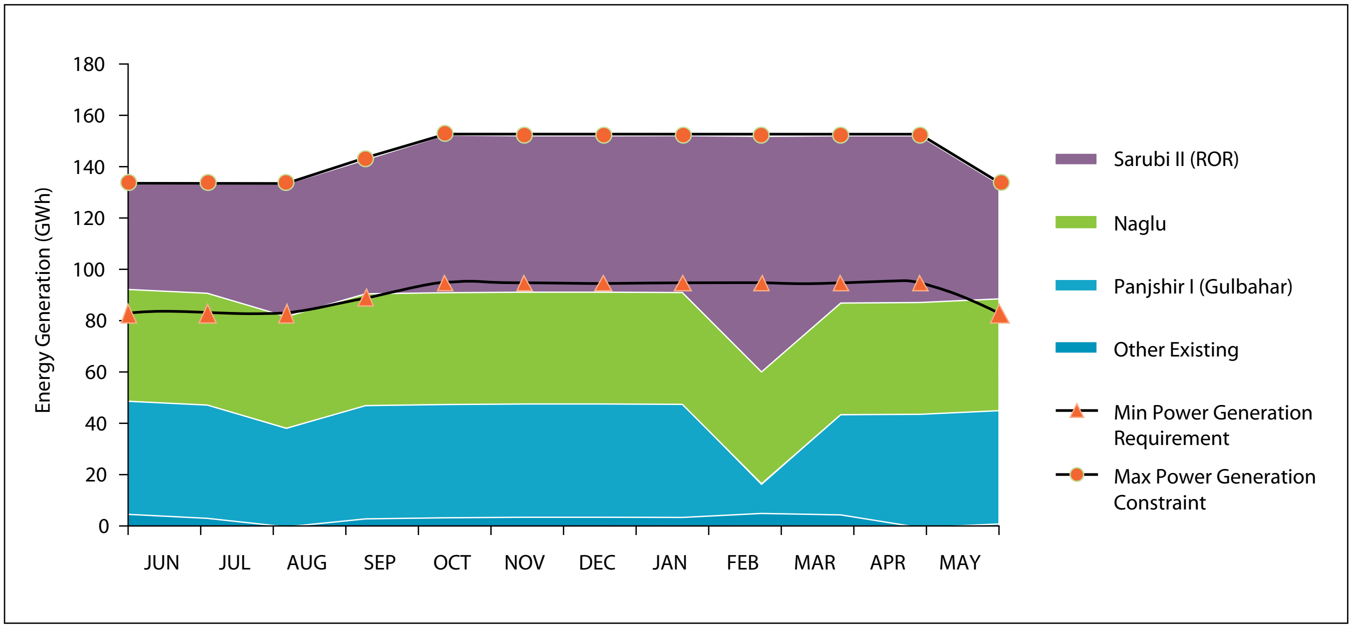
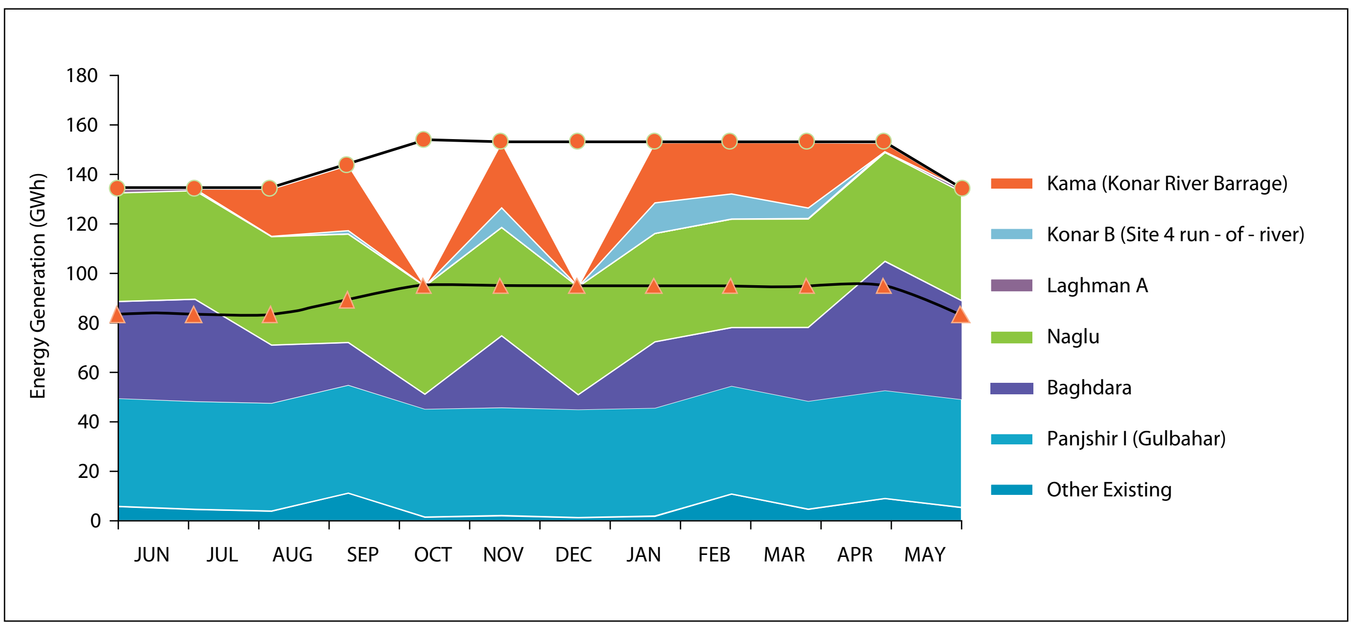
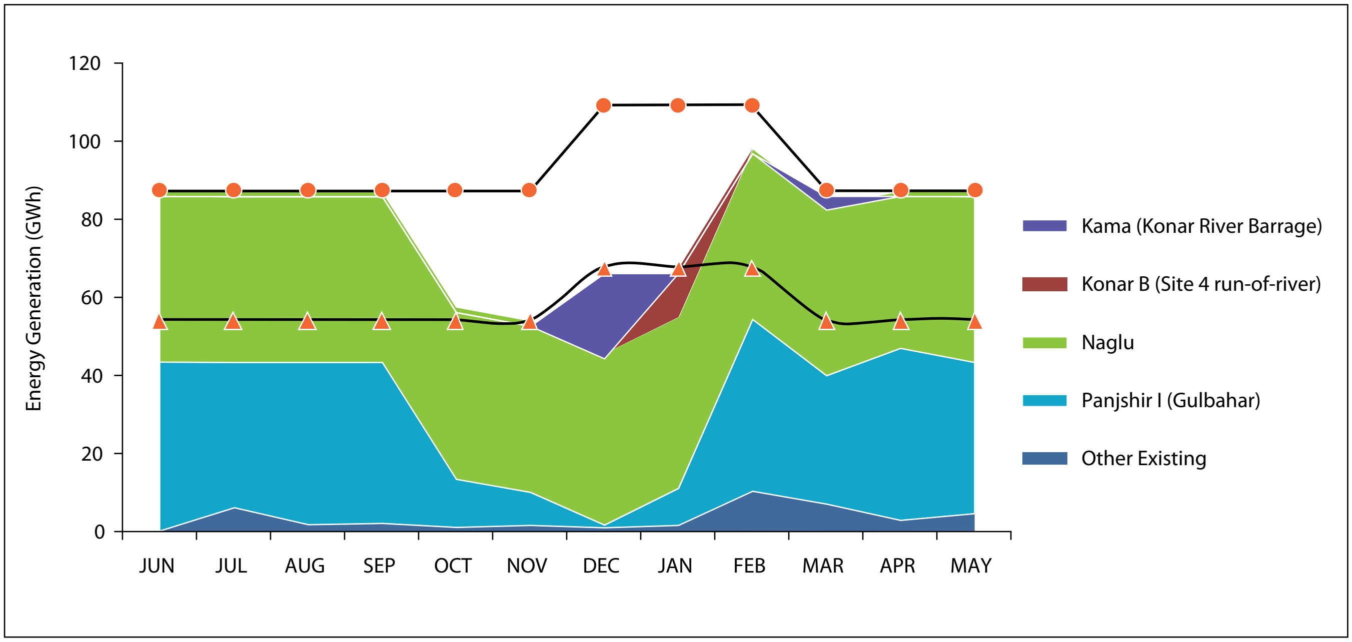



**Figure E.21:** Base Case with Energy Demand Alternative A: Without Konar A and Sarobi II; Naglu=100MW




generation increases by approximately 16 percent. Storage developed is just one-third that developed in the scenario in figure E.23; irrigation development in the Panjshir subbasin decreases 42 percent (it remains the same in the other subbasins. Basin plan investment cost decreases by 21 percent, but net economic benefit increases by 10 percent. This suggests that the optimal result shown in figure E.23 is a very efficient basin hydropower system plan for an electricity production system configured as in Alternative B. More detailed operations studies may provide a basis for avoiding the development of the two run-of-river sites in figure E.23 since they add nearly one-third to the cost of dams and hydropower and are not needed most of the year.

**Figure E.23:** Base Case with Energy Demand Alternative B: Without Konar A and Sarobi II' Naglu=100MW




The results for the Base Case, alternative demand scenarios, and alternative generating systems with the Kabul Medium-Term Plan (Kabul population of 6 million and no Parwan groundwater in table E.2) are summarized in table E.3. Basin irrigation development remains constant but is approximately 6 percent below the maximum, with the decrease confined to the Logar-Upper Kabul subbasin. There is no change in the cost or sources of Kabul water supply.

In the Base Case with hydropower alone, the run-of-river options on the Konar River provide approximately 9 percent of winter season energy, increasing the total investment cost by approximately 11 percent. These options are not required in the Alternative A demand scenario and the hydro-thermal system unless the Sarobi II option is dropped, in which case they provide approximately 18 percent of the winter season energy and, with the addition of Baghdara, increase the basin investment cost by approximately 21 percent over the case without the Konar storage option. Hence, the mixed hydro-thermal system and the Alternative A demand scenario would appear to be the best choice for a middle-term energy production expansion plan, beginning with Panjshir I and adding Sarobi II as demand rises. The need to construct and commission Baghdara or the run-of-river options on the Konar River can be avoided if the hydropower cascade is allocated a smaller share of peak winter energy demand. Under Alternative A, the share is approximately 53 percent of the January peak energy demand.

The storage developed at Panjshir I at the head of the cascade is just over 400 million cubic meters under the Kabul Medium-Term Plan and would result in a dam with an estimated height of 135 meters above the bed of the river. This would result in substantial resettlement in the reservoir area. The run-of-river options on the Konar River will also encounter substantial resettlement, especially the lower option at Kama, which also functions as irrigation headworks. In this case, therefore, significant cost revisions may be necessary and these scenarios would have to be reassessed.

## Single-Purpose or Multipurpose Storage in the Panjshir

Since the 1970s, a storage option in the Panjshir subbasin has been seen as an important element of the Kabul River basin development strategy. The argument has surged back and forth between an essentially single-purpose storage and hydropower project at Baghdara, where the Panjshir River enters a gorge before joining the Upper Kabul River (too far downstream on the Panjshir River to provide irrigation or Kabul water supply benefits), and a

**Table E.3 Alternative Basin Energy Production Systems**

| Urban demand | Kabul Medium-Term Plan (KMTP) | | | | |
|---|---|---|---|---|---|
| **Energy demand** | **Base Case** | | **Alternative A** | | |
| **Electricity supply system** | **Hydropower** | | **Hydro-thermal system** | | |
| **Hydropower options** | **All** | **No Konar** | **All** | **No Konar** | **No Konar & Sarobi II** |
| Basin gross economic benefits (M$/yr) | 352.8 | 326.7 | 372.8 | 372.8 | 346.9 |
| Basin net economic benefits (M$/yr) | 98.0 | 42.2 | 130.5 | 123.6 | 42.6 |
| Basin investment cost ($m) | 2,571.9 | 2,867.3 | 2,448.9 | 2,516.6 | 3,062.7 |
| Basin power benefits (M$/yr) | 119.8 | 93.8 | 139.8 | 139.8 | 111.9 |
| Max. annual energy demand (GWH) | 2,179.7 | 2,179.7 | 1,747.2 | 1,747.2 | 1,747.2 |
| Annual energy generated (GWH) | 2,179.3 | 1,943.3 | 1,747.3 | 1,747.7 | 1,716.4 |
| Energy generated at Panjshir I | 249.6 | 509.3 | 295.9 | 482.1 | 525.6 |
| Energy generated at Baghdara | 0.0 | 0.0 | 0.0 | 0.0 | 281.4 |
| Energy generated at Naglu | 480.0 | 481.8 | 481.8 | 473.9 | 525.6 |
| Energy generated at Sarobi II (ROR) | 685.6 | 723.9 | 634.7 | 733.8 | 0.0 |
| Energy generated at Konar A | 718.7 | 0.0 | 284.4 | 0.0 | 0.0 |
| Energy generated at Konar B (ROR) | 0.0 | 56.8 | 0.0 | 0.0 | 99.6 |
| Energy generated at Kama (ROR) | 0.0 | 115.6 | 0.0 | 0.0 | 218.3 |
| Total storage developed (MCM) | 567.1 | 484.5 | 434.1 | 477.8 | 577.0 |
| Storage at Panjshir I | 292.4 | 411.0 | 292.4 | 404.3 | 418.6 |
| Investment cost of storage (M$) | 1,064.2 | 1,359.4 | 940.9 | 1,008.6 | 1,554.8 |
| Basin irrigated area (ha) | 177,367 | 177,367 | 177,367 | 177,367 | 177,367 |
| Basin net irrigation benefits (M$/yr) | 115.8 | 115.8 | 115.8 | 115.8 | 117.7 |
| Annual cost of Kabul BWS (M$/yr) | 51.1 | 51.1 | 51.1 | 51.1 | 51.1 |
| Investment cost of Kabul BWS (M$) | 443.5 | 443.7 | 443.8 | 443.8 | 443.7 |

Note: *Base Case Aynak water demand = 43 MCM/yr; Kabul environmental flow requirement = 1m$^3$/s; Irrigation investment cost = $6,000/ha; Irrigation efficiency = 45%; Naglu = 100 MW.*

*KMTP: Kabul Medium-Term Plan (population 6 million; no Panjshir groundwater).*

*ROR: run-of-river.*

*BWS: bulk water supply.*

multipurpose project upstream near Gulbahar,[79] where the Panjshir River leaves the narrow upper valley and enters the Shomali Plain. The argument stems in large part from the narrow sector approach to project planning and selection that has prevailed in Afghanistan since 2002.

At the time of the preparation of the Kabul River Basin Master Plan in 1978, the unit costs of storage at Baghdara were the lowest in the basin, and the storage capacity of the site (859 million cubic meters) and the proposed installed generating capacity (280 megawatts) were large. Hence in 2002, when the Ministry of Energy (later evolved to form the Ministry of Energy and Water) needed to launch a major hydropower investment to overcome the severe power shortage in Kabul and the rest of the country, Baghdara was a natural first choice, especially as the expansion of electricity generation capacity was the primary criterion. There had been no comprehensive and integrated modeling or analysis of water supply and demand in the Kabul River basin since the original Kabul River Basin Master Plan studies; hence the importance of other demands on the water resources of the Panjshir subbasin could not be assessed to determine the priorities among different storage and hydropower options. However, the recently completed prefeasibility study of the Baghdara option (Fichtner Consulting Engineers 2007) suggests that this option may be much more expensive than other options, thus

[79] Two sites were identified in the narrow upper valley of the Panjshir River: an upstream site called Barak and the lower site near Gulbahar. There are three possible axes for this site, referred to as Panjshir I, II, and III. This study has used the favored Panjshir I site.

| Table E.4 Multipurpose or Single-Purpose Storage in the Panjshir Subbasin | | | | |
|---|---|---|---|---|
| | **Base Case (Naglu = 100 MW)** | | | |
| | **With upstream multipurpose storage** | | | **Without upstream multipurpose storage (No Panjshir I & Barak)** |
| | **No Konar A** | **No Konar A & Sarobi II** | **No Konar A & Sarobi II Kabul pop. = 8 million No Panjshir groundwater** | **No Konar A & Sarobi II Kabul pop. = 8 million No Panjshir groundwater** |
| Gross economic benefits (M$) | 332.3 | 313.4 | 305.1 | 241.8 |
| Net economic benefits (M$/yr) | 54.2 | 25.7 | 1.6 | –34.2 |
| Basin plan investment cost (M$) | 2,719.2 | 2,796.2 | 3,170.5 | 2,797.3 |
| Total storage developed (MCM) | 472.0 | 570.4 | 569.5 | 371.9 |
| Investment cost of storage (M$) | 1,331.3 | 1,432.6 | 1,427.5 | 1,290.7 |
| Hydropower energy production (GWh/yr) | 1,787.2 | 1,610.0 | 1,700.2 | 1,543.1 |
| Irrigated area in Panjshir subbasin (ha) | 74,530.0 | 74,530.0 | 74,530.0 | 37,739.0 |
| Irrigated area in Logar-Upper Kabul subbasin (ha) | 21,099.0 | 21,099.0 | 16,101.0 | 16,101.0 |
| Incremental Kabul water supply from Panjshir subbasin (MCM) | 142.8 | 111.0 | 187.8 | 187.6 |
| Avg. incremental unit cost of Kabul water supply ($/m$^3$) | 0.303 | 0.265 | 0.291 | 0.307 |

*Note: Upstream = Panjshir River upstream of the Baghdara project site (see figure 4.1).*

reigniting the argument about which option should be a priority.[80]

Table E.4 compares the results under the Base Case (original energy demand as in chapter 4 with Naglu rehabilitation completed), with and without upstream multipurpose storage on the Panjshir River. The upstream connotation refers to sites upstream of the Baghdara site. First, three different scenarios with upstream multipurpose storage options are compared. The three scenarios correspond to No Konar A option, No Konar A and Sarobi II options, and No Konar A and Sarobi II options with a high Kabul population (8 million) and no Panjshir subbasin groundwater. This last scenario places the maximum surface water demand on the Panjshir subbasin.

a. The gross economic benefit declines as demand on the Panjshir subbasin increases, and more importantly, net economic benefit of the basin investment plan declines from $54.2 million per year to remaining barely above zero.

b. In the scenario without Konar A but with Sarobi II, Panjshir I storage is at the maximum for these three scenarios (344.1 million cubic meters) and energy generation is 423 gigawatt-hours; the largest energy producer in the basin hydropower system under this scenario is Sarobi II (643 gigawatt-hours with 220 megawatts installed capacity).

c. Energy generation at Naglu is practically constant under all three scenarios at 525 gigawatt-hours, and the combined energy generation at Panjshir I and Barak ranges from 810 to 819 gigawatt-hours under the scenario with high Kabul population and no Panjshir groundwater.

d. Irrigated area remains constant under all three scenarios in the Panjshir subbasin, but decreases in the Logar-Upper Kabul subbasin by 24 percent as the surface water supply to Kabul increases

[80] New technical studies of the Panjshir I (Gulbahar) project are expected to begin in 2008.

to compensate for the nonavailability of Panjshir groundwater.

In the last column of table E.4, the multipurpose options upstream of Baghdara are dropped but all other assumptions are the same as in the third scenario, namely the nonavailability of Konar A, Sarobi II, or Panjshir subbasin groundwater and Kabul's population at 8 million. This causes several significant changes:

a. Gross economic benefit without upstream multipurpose storage decreases from $305 million to $242 million, and annual net economic benefits decrease to –$34 million per year, suggesting as a first approximation that this scenario does not result in a feasible basin investment plan.

b. The cost of the basin investment plan decreases, but 60 percent of that decrease is due to reduced irrigated area.

c. The irrigated area remains the same in the Logar-Upper Kabul subbasin, but decreases dramatically in the Panjshir subbasin by 49 percent.

d. The total energy produced in the scenario without multipurpose storage is approximately 9 percent below that with multipurpose storage, and is the lowest among all the scenarios in table E.4. Energy production is concentrated at Baghdara (638 gigawatt-hours) and energy production at Naglu decreases to 501 gigawatt-hours.

Overall, these results strongly indicate that a multipurpose option in the Panjshir subbasin is essential from an economic and multisectoral development perspective. However, before a definitive choice is made, the cost of all options needs to be reassessed and brought up to date in order to conduct this analysis with more accurate inputs.

Resettlement and relocation issues similar to those that affect the Baghdara option may also be important for consideration of the Panjshir I option. Across the range of scenarios considered in this study, the live storage at Panjshir I ranges from 210 million to approximately 464 million cubic meters (under the highest energy demand scenarios), and the maximum reservoir level ranges from about 100 meters to 143 meters above the river bed. Above roughly 100 meters, the reservoir begins to encroach on a section of the Panjshir valley that is wider and more intensively cultivated and where a small town is located. Since the reservoir essentially blocks the entrance to the valley, a difficult relocation of the main road in the valley would also be necessary.

## Irrigation Development Options

Irrigation development demand in the Kabul River basin is represented by the existing (annual and intermittent) and potential irrigated areas aggregated into 14 demand nodes in the DSS. These cover 106,320 hectares in the Logar-Upper Kabul subbasin;[81] 73,300 hectares in the Panjshir subbasin; and 136,530 hectares in the Lower Kabul subbasin (referred to as Nangarhar in the DSS). The purpose is to represent the aggregate water demand from these areas in reasonable relation to the potential sources of water. The DSS results indicate target area, cropping pattern, and bulk water allocation with an assumed return flow. These aggregate results need to be translated into specific projects with the necessary headworks, conveyance, and distribution and control facilities. The total investment cost for such a package of irrigation projects at each node is estimated by multiplying the assumed unit investment cost ($6,000 per hectare) by the target area at that node.

The maximum irrigation development occurs under the Base Case (90 percent reliable water supply), with approximately 183,000 hectares producing direct economic benefit of $123 million per year. The net present value of irrigation benefits is approximately $135 million, based on the assumed average unit investment cost of $6,000 per hectare. The variation in total irrigated area in the basin, and irrigated area developed in the Panjshir and Logar-Upper Kabul subbasins, is shown in figure E.24 for a range of scenarios:

a. Base Case with 90 percent reliability (as in all scenarios below);

b. Base Case with higher costs (as in figure E.8);

[81] The total area of 106,320 hectares includes 37,300 hectares located south and east of Kabul that can only be irrigated with treated wastewater and urban runoff from Kabul. The model assumes the wastewater flows from Kabul are 40 percent of the bulk water supply to Kabul. Urban runoff is not presently included. If the wastewater flows in the months of November to May can be stored, the total area than can be irrigated is about 5,000–6,000 hectares under this assumption and a range of scenarios.

**Figure E.24:** Irrigation Development Options in the Panjshir and Logar-Upper Kabul Sub-basins

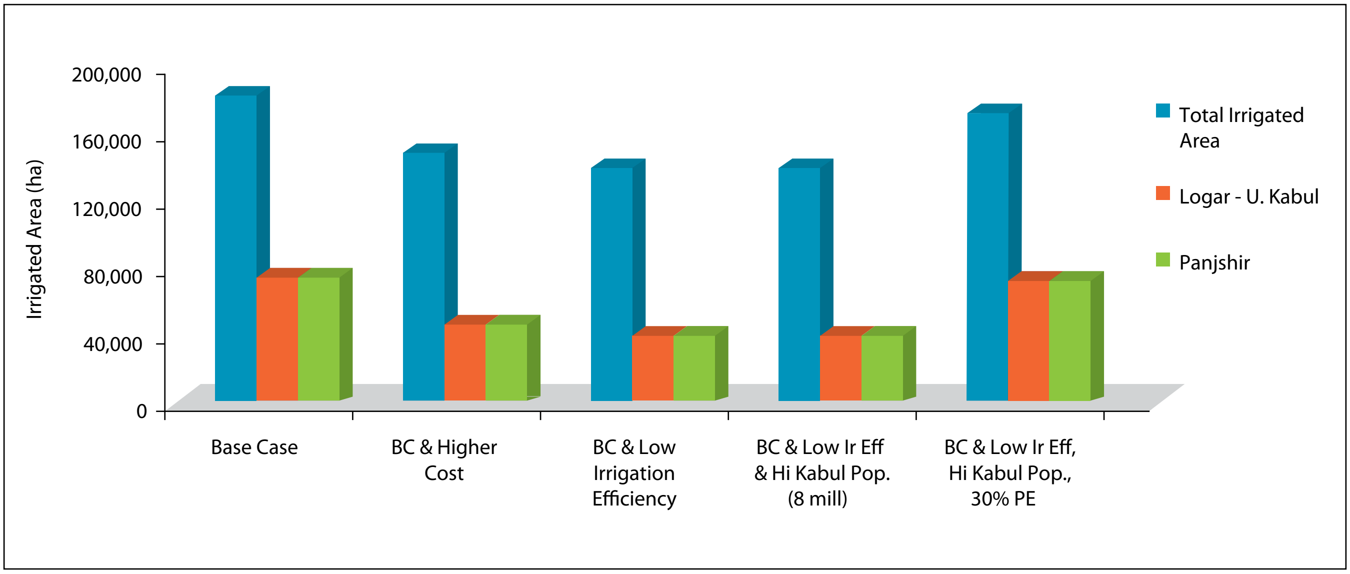



**Table E.5 Significance of Efficiency and Investment Cost in Irrigation Development**

| | Base Case | | | |
|---|---|---|---|---|
| | **High Eff/High Cost e = 45% c = $6,000/ha** | **High Eff/Low Cost e = 45% c = $4,000/ha** | **Low Eff/High Cost e = 35% c = $6,000/ha** | **Low Eff/Low Cost e = 35% c = $4,000/ha** |
| Gross economic benefits (M$) | 362.5 | 368.1 | 287.3 | 353.6 |
| Total net benefits (M$/yr) | 107.9 | 150.1 | 92.0 | 125.5 |
| Total net irrigation benefits (M$/yr) | 121.8 | 166.3 | 74.9 | 155.3 |
| Total irrigated area (ha) | 1,82,930 | 1,86,133 | 1,40,067 | 1,77,976 |
| Irrigated area: Logar-U. Kabul (ha) | 21,099 | 24,302 | 14,882 | 18,844 |
| Irrigated area: Panjshir (ha) | 74,530 | 74,530 | 39,834 | 73,781 |

c. Base Case with low irrigation efficiency (35 percent);

d. Base Case with low irrigation efficiency and high Kabul demand (population 8 million);

e. Base Case with low irrigation efficiency, high Kabul demand and 30 percent power exports.

The irrigated areas in the Lower Kabul subbasin remain nearly constant at the maximum potential except for a slight decline of approximately 2 percent if average irrigation efficiency does not improve above 35 percent. This large area, of about 87,300 hectares, is in an advantageous location from the point of view of reliable bulk water supply and climate in the lower basin with no other significant competing water demands.

The irrigated areas in the Logar-Upper Kabul subbasin and in the Panjshir subbasin decrease from the level of the Base Case when costs are higher (because storage decreases), irrigation efficiency is lower, and when low irrigation efficiency is combined with high Kabul population of 8 million people. The irrigated area in the Panjshir subbasin increases to approximately 97 percent of the maximum level when energy demand is increased by 30 percent power exports because multipurpose storage increases in the Panjshir subbasin.

Table E.5 shows a comparison of four scenarios based on the Base Case in which the average irrigation efficiency (e) and the average investment cost (c) of irrigation development are varied.

f. If the assumed irrigation efficiency is high, lowering the average irrigation investment cost by one third increases the irrigated area in the Logar-Upper Kabul subbasin by 15 percent, but there is no change in the other subbasins because they are already at the maximum irrigated area. The net economic benefit increases by 38 percent and net irrigation benefits increase by 37 percent.

g. If irrigation efficiency is lowered to 35 percent, then with average irrigation investment costs of $6,000 per hectare the irrigated area decreases by 23 percent, and both net basin economic benefit and net irrigation benefit decline.

h. If irrigation efficiency does not improve above 35 percent but average irrigation investment cost decreases by one third to $4,000 per hectare, then irrigated area increases by 27 percent to a level nearly equal to the Base Case, net irrigation benefits increase over 100 percent, and net basin economic benefit increases by 36 percent.

As discussed before, the presence or absence of multipurpose storage in the Panjshir subbasin strongly influences the level of irrigation development in the upper Kabul River basin. Table E.5 shows that the ability to achieve key improvements in irrigation efficiency and managing investment costs of irrigation have an even more dominant effect on the level of irrigation development in the basin.

Table E.6 presents the results for scenarios developed from the Base Case (see table 6.1), but with different modes of energy production. These scenarios represent the Kabul Medium-Term Plan (Kabul 6 million population and no Parwan groundwater in table E.2), along with two alternative energy production and demand scenarios: one with an all hydropower electricity production system and Base Case energy demand, and the second with a hydro-thermal electricity production system under demand Alternative A.

Again, it can be seen that the key parameters governing the development of irrigation are irrigation efficiency and average cost of development. In the Panjshir subbasin irrigated area decreases by 48 percent when overall irrigation efficiency is limited to 35 percent. Lower values of irrigation efficiency do not yield a feasible result. Irrigation development in the Logar River valley is sensitive to both the allocation of water from the Logar River to Kabul and to irrigation efficiency. The effect is the same under both

**Table E.6 Influence of Strategic Scenario and Irrigation Efficiency on Irrigation Development**

| Base Case | | | | | | |
|---|---|---|---|---|---|---|
| **Urban demand** | **Kabul Medium-Term Plan (population = 6 million; no Panjshir groundwater)** | | | | | |
| **Energy production & demand** | **Hydropower only Base Case demand** | | | **Hydro-thermal system Demand Alternative A** | | |
| **Surface water allocated to Kabul from Logar River** | **Yes** | **No** | **No** | **Yes** | **No** | **No** |
| **Irrigation efficiency** | **High** | **High** | **Low** | **High** | **High** | **Low** |
| Basin gross economic benefits (M$/yr) | 352.8 | 363.1 | 289.9 | 372.8 | 383.13 | 354.49 |
| Basin net economic benefits (M$/yr) | 98.0 | 95.8 | 76.8 | 123.6 | 121.6 | 88.8 |
| Basin net irrigation benefits (M$/yr) | 115.8 | 122.2 | 76.5 | 115.8 | 122.2 | 104.5 |
| Investment cost of Kabul BWS (M$) | 443.5 | 543.4 | 563.2 | 443.8 | 543.7 | 564.0 |
| Total annual cost of Kabul BWS (M$/yr) | 51.1 | 63.9 | 66.7 | 51.1 | 63.9 | 66.5 |
| SW to Kabul from Logar-U. Kabul (MCM/yr) | 81.8 | 14.7 | 4.5 | 82.0 | 14.7 | 4.5 |
| Basin irrigated area (ha) | 177,367 | 183,286 | 141,565 | 177,367 | 183,286 | 167,237 |
| Irrigated area: Logar River valley (ha) | 8,090 | 14,009 | 10,158 | 8,090 | 14,009 | 8,090 |
| Irrigated area: Panjshir subbasin (ha) | 74,530 | 74,530 | 38,987 | 74,530 | 74,530 | 66,727 |

*Note:* *Base Case Aynak water demand = 43 MCM/yr; Kabul environmental flow requirement = 1m$^3$/s.*
*Base Case irrigation investment cost = $6,000/ha.*
*Base Case irrigation efficiency = 45%; low efficiency = 35%.*
*SW = surface water.*

energy production and demand scenarios, and irrigation development in the Upper Kabul supplied from the Haijan reservoir is the same in all cases in table E.6. Irrigated area in the Logar River valley increases by approximately 73 percent when no water is allocated to Kabul from the Logar River, but then declines from that high level by 27 percent if the overall average irrigation efficiency is low at 35 percent. The increase stems from a nearly fivefold increase in reservoir storage capacity at Kajab on the upper Logar River when no water from the Logar River is allocated to Kabul. The reservoir capacity declines from this high level by approximately 36 percent when irrigation efficiency is low.

Lowering the overall average investment cost of irrigation development from the Base Case value of $6,000 per hectare to $4,000 per hectare would have a dramatic effect on the reduction in irrigated area that results when irrigation efficiency is low. The decrease in the Logar River valley would be half, or approximately 14 percent, and the decrease would be only around 5 percent in the Panjshir subbasin, in the case of the hydropower energy production system, which is the most constrained.

No attempt has been made in this study to allocate the storage costs among the beneficial purposes served by individual storage options and to determine the total storage cost component of sector costs. For example, the storages in the Logar-Upper Kabul subbasin support the provision of surface water to the Aynak mine, irrigation, and drinking water supply to Kabul. Similarly, the storage at Panjshir I supports the provision of water to Kabul, irrigation, and energy production. While cost allocation to each sector would make no difference to the overall solution, it could make a difference in comparing and assessing alternative sector investments.

## Environmental Flow Requirements

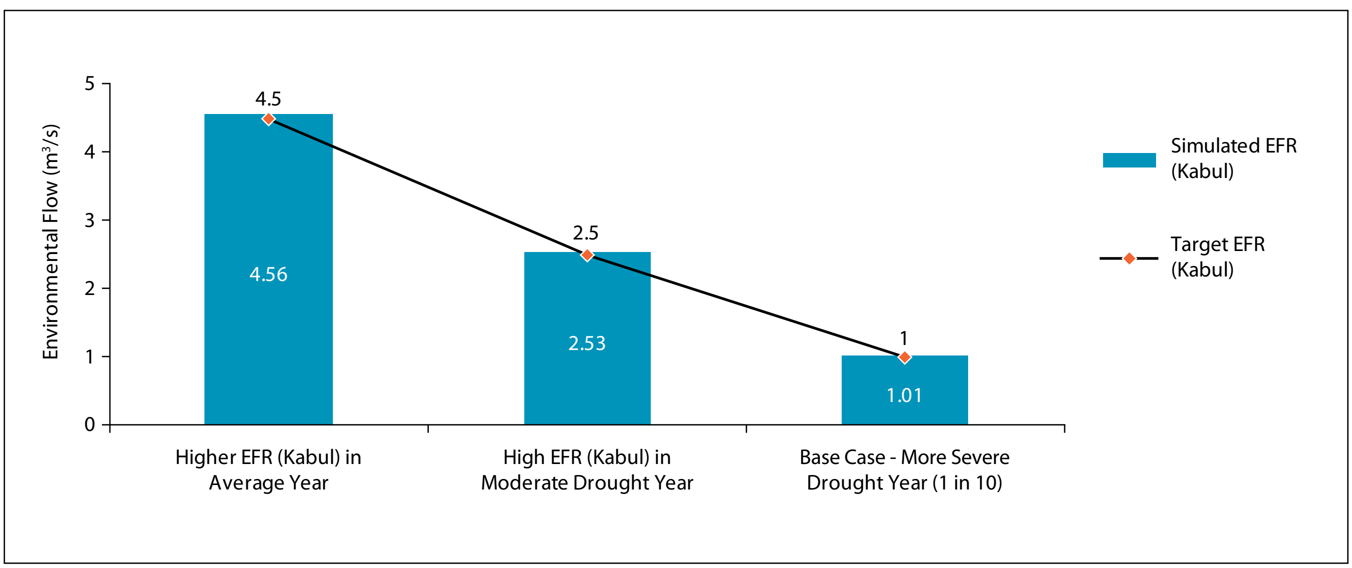
Two main environmental flow requirements are included in this analysis:

a. Sufficient flow to maintain the Kole Hashmat Khan Waterfowl Sanctuary near Kabul. This flow is defined as the volume of water required to maintain a constant volume of water in the sanctuary (evapotranspiration less precipitation) for a given sanctuary area.

b. Sufficient flow to provide a minimum monthly average flow in the Kabul River as it flows through Kabul.

There is little information on the current status of the Kole Hashmat Khan Waterfowl Sanctuary. The area has been neglected, and is subject to encroachment from both urban and agricultural land uses, including encroachment

**Figure E.25:** Feasible Environmental Flow Requirements Kabul River through Kabul City



onto the hydrological links with the Logar River. The government has not indicated whether it is intends to preserve this cultural and natural landmark. In this study, a relatively large area of 1,000 hectares has been assumed for the sanctuary, and the water requirement to maintain this area is about 0.83 million cubic meters per month or about 0.33 cubic meters per second, with the Logar River as the assumed source.

Three scenarios for the Kabul River environmental flow requirement through Kabul City are compared in figure E.25. Each scenario is based on the Base Case (table 6.1) but with different streamflow reliability. The reason is that the three target environmental flow requirements represent the upper limit for the given flow reliability, that is at 90 percent reliability an environmental flow requirement for the Kabul River greater than 1 cubic meter per second is not feasible. Similarly, for 80 percent reliable streamflows, the maximum feasible target environmental flow requirement is 2.5 cubic meters per second. The actual simulated annual average flow is 2.53 cubic meters per second, and for the higher target of 4.5 cubic meters per second, which is only feasible for the case of mean annual flows, the simulated average flow is 4.56 cubic meters per second.

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