Conceptual Model of Water Resources in the Kabul Basin, Afghanistan

By Thomas J. Mack, M. Amin Akbari, M. Hanif Ashoor, Michael P. Chornack, Tyler B. Coplen, Douglas G. Emerson, Bernard E. Hubbard, David W. Litke, Robert L. Michel, L. Niel Plummer, M. Taher Rezai, Gabriel B. Senay, James P. Verdin, and Ingrid M. Verstraeten

Prepared in cooperation with the Afghanistan Geological Survey under the auspices of the U.S. Agency for International Development

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Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)
meter per day (m/d)	3.281	foot per day (ft/d)
meter per year (m/yr)	3.281	foot per year (ft/yr)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second per square kilometer [$(m^3/s)/km^2$]	91.49	cubic foot per second per square mile [$(ft^3/s)/mi^2$]
cubic meter per day (m^3/d)	35.31	cubic foot per day (ft^3/d)
liter per second (L/s)	15.85	gallon per minute (gal/min)
cubic meter per day (m^3/d)	264.2	gallon per day (gal/d)
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
	Hydraulic conductivity	
meter per day (m/d)	3.281	foot per day (ft/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Datums

Vertical and horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84).

Altitude, as used in this report, refers to distance above the vertical datum.

Acronyms and Abbreviations Used in Report

AET	actual evapotranspiration due to irrigation water use
AGROMET	Afghanistan Ministry of Agriculture, Irrigation, and Livestock; Afghanistan Meteorological Authority, U.S. Agency for International Development (USAID), U.S. Geological Survey
AGS	Afghanistan Geological Survey
AIMS	Afghanistan Information Management Services
ASL	above sea level
ASTER	advanced spaceborne thermal emission and reflection radiometer
AVHRR	advanced very-high-resolution radiometer
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe; German Federal Institute for Geosciences and Natural Resources
CFCs	chlorofluorocarbons
DACAAR	Danish Committee for Aid to Afghanistan Refugees
DEM	digital elevation model
EDC	U.S. Geological Survey, EROS Data Center
ET	evapotranspiration
EVI	enhanced vegetation index
FA	filter acidified
FAO	Food and Agriculture Organization
FU	filter unacidified
GDAS	global assimilation system
GIS	geographic information system
JICA	Japan International Cooperation Agency
IAEA	International Atomic Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
LPDAAC	Land Processes Distributed Active Archive Center
LST/E	land-surface temperature/emissivity
MEW	Afghanistan Ministry of Energy and Water
MMI	Afghanistan Ministry of Mines and Industries (now known as Afghanistan Ministry of Mines (MOM)
MODIS	moderate-resolution imaging spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	normalized difference vegetation index
NGO	non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
NSIDC	National Snow and Ice Data Center

Acronyms and Abbreviations Used in Report—Continued

NWQL	National Water-Quality Laboratory
SRTM	shuttle radar topography mission
SSEB	simplified surface-energy balance
SWE	snow water equivalent
SWIR	short wavelength infrared (1.0 - 2.5 micron coverage for advanced spaceborne thermal emission and reflection radiometer (ASTER))
TIR	thermal infrared (8.0–14.0 micron coverage for advanced spaceborne thermal emission and reflection radiometer (ASTER))
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
USAID	United States Agency for International Development
USGS	United States Geological Survey
VI	vegetation index
VNIR	visible and near-infrared reflectance (0.4–1.0 micron coverage for advanced spaceborne thermal emission and reflection radiometer (ASTER))
WHO	World Health Organization
WMO	World Meteorological Organization

Place Names

Place names given in this report are Anglicized translations from the Dari language; however, there may not be a universally accepted English language translation for many names. This report attempts to use the most commonly used translation where possible, but the reader is cautioned that other variants of names may be in use.

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Abstract

The United States (U.S.) Geological Survey has been working with the Afghanistan Geological Survey and the Afghanistan Ministry of Energy and Water on water-resources investigations in the Kabul Basin under an agreement supported by the United States Agency for International Development. This collaborative investigation compiled, to the extent possible in a war-stricken country, a varied hydrogeologic data set and developed limited data-collection networks to assist with the management of water resources in the Kabul Basin. This report presents the results of a multidisciplinary water-resources assessment conducted between 2005 and 2007 to address questions of future water availability for a growing population and of the potential effects of climate change.

Most hydrologic and climatic data-collection activities in Afghanistan were interrupted in the early 1980s as a consequence of war and civil strife and did not resume until 2003 or later. Because of the gap of more than 20 years in the record of hydrologic and climatic observations, this investigation has made considerable use of remotely sensed data and, where available, historical records to investigate the water resources of the Kabul Basin. Specifically, this investigation integrated recently acquired remotely sensed data and satellite imagery, including glacier and climatic data; recent climate-change analyses; recent geologic investigations; analysis of streamflow data; groundwater-level analysis; surface-water- and groundwater-quality data, including data on chemical and isotopic environmental tracers; and estimates of public-supply and agricultural water uses. The data and analyses were integrated by using a simplified groundwater-flow model to test the conceptual model of the hydrologic system and to assess current (2007) and future (2057) water availability.

Recharge in the basin is spatially and temporally variable and generally occurs near streams and irrigated areas in the late winter and early spring. In irrigated areas near uplands or major rivers, the annual recharge rate may be about 1.2×10^{-3} meters per day; however, in areas at lower altitude with little irrigation, the recharge rate may average about 0.7×10^{-3} meters per day. With increasing population, the water needs of the Kabul Basin are estimated to increase from 112,000 cubic meters per day to about 725,000 cubic meters per day by the year 2057. In some areas of the basin, particularly in the north along the western mountain front and near major rivers, water resources are generally adequate for current needs. In other areas of the basin, such as in the east and away from major rivers, the available water resources may not meet future needs. On the basis of the model simulations, increasing withdrawals are likely to result in declining water levels that may cause more than 50 percent of shallow (typically less than 50 meters deep) supply wells to become dry or inoperative. The water quality in the shallow (less than 100 meters thick), unconsolidated primary aquifer has deteriorated in urban areas because of poor sanitation. Concerns about water availability may be compounded by poor well-construction practices and lack of planning.

Future water resources of the Kabul Basin will likely be reduced as a result of increasing air temperatures associated with global climate change. It is estimated that at least 60 percent of shallow groundwater-supply wells would be affected and may become dry or inoperative as a result of climate change. These effects of climate change would likely be greatest in the agricultural areas adjacent to the Paghman Mountains where a majority of springs, karezes, and wells would be affected. The water available in the shallow primary aquifer of the basin may meet future water needs in the northern areas of the Kabul Basin near the Panjsher River. Conceptual groundwater-flow simulations indicate that the basin likely has groundwater reserves in unused

unconsolidated to semiconsolidated aquifers that are as thick as 1,000 meters. On the basis of mass-fraction measurements of chlorofluorocarbon and carbon 14 analysis in few samples, the age of groundwater in deep aquifers is likely on the order of thousands of years and may differ among the subbasins of the Kabul Basin. Deep groundwater in subbasin areas that are bounded by interbasin ridges may be considerably older than deep groundwater in other areas of the Kabul Basin. The deep aquifer may sustain increased municipal use but may not support increased agricultural use, which is presently an order of magnitude greater than municipal water use. The hydraulic feasibility of deep groundwater extractions and the quality of groundwater in the deep aquifer, however, are not well known and are currently (2007) under investigation.

Introduction

The availability of water resources is vital to the social and economic well-being and rebuilding of Afghanistan. With refugees returning during periods of relative security, the city of Kabul in 2006 had a population of about 4 million. Rapid population growth and changing climate conditions have placed new stresses on limited water resources and have resulted in thousands of dry or inoperative wells in recent years. Projections of central and west Asia as vulnerable to climate change (Cruz and others, 2007) and observations of diminishing glaciers, a primary source of water in the region, have led to heightened concerns regarding future water availability in the Kabul Basin of Afghanistan. In recent years, Afghan ministries together with nongovernmental organizations (NGOs), humanitarian-aid agencies, and foreign technical agencies have been investigating the water resources of Afghanistan.

In 2004, the United States (U.S.) Geological Survey (USGS), under an agreement supported by the U. S. Agency for International Development (USAID), began collaboration with the Afghanistan Geological Survey (AGS) and the Afghanistan Ministry of Energy and Water (MEW). The USGS and AGS have been working together to compile hydrogeologic data and to develop data-collection networks necessary for the understanding and management of Afghanistan's water resources. The initial focus of the AGS-USGS collaboration was on training and capacity (skill) building while a hydrologic database was developed. This collaboration resulted in USGS publications on groundwater resources (Broshears and others, 2005) and groundwater levels (Akbari and others, 2007) in the Kabul Basin (fig. 1). Continued collaboration between the USGS and AGS under a USAID funding agreement (number 07C442100KB) led to a wider involvement of researchers in different disciplines to provide an assessment of water-resources availability in the Kabul Basin. Renewed scientific investigations and data-collection efforts have been conducted by the USGS to better determine Afghanistan's natural resources.

Purpose and Scope

This report describes water availability in the Kabul Basin of Afghanistan on the basis of climatic analysis, glacier extent, hydrogeology, streamflow, groundwater levels, groundwater quality and sources of recharge, and water use. The report includes documentation of the data-collection and analytical methods and the results of analyses that can be used in the management of water resources in the Kabul Basin. The report also includes a description of a conceptual groundwater-flow model that can be used to assess components of the groundwater-flow system and to estimate water availability in the Kabul Basin. Water resources for 2006–07 are described and projected water-resources availability is presented with respect to needs generated by an increasing population and potential climate change. Fourteen appendixes are included that provide more detailed discussions of selected topics presented in the main body of the text.

The scope of this investigation was regional, encompassing the valley formed by the geologic basin extending from the city of Kabul approximately 80 km north to the Bagram area (fig. 1). The information collected and presented in this investigation was constrained by the many difficulties and limitations of working in a war-stricken country. Because it was developed primarily with historical data, the groundwater-flow model is designed to test only the understanding of the hydrologic system, or conceptual model. Results of model runs of future scenarios presented in this report are based on information available from recent planning or climatic studies and can be used to enhance the conceptual understanding of water resources of the Kabul Basin.

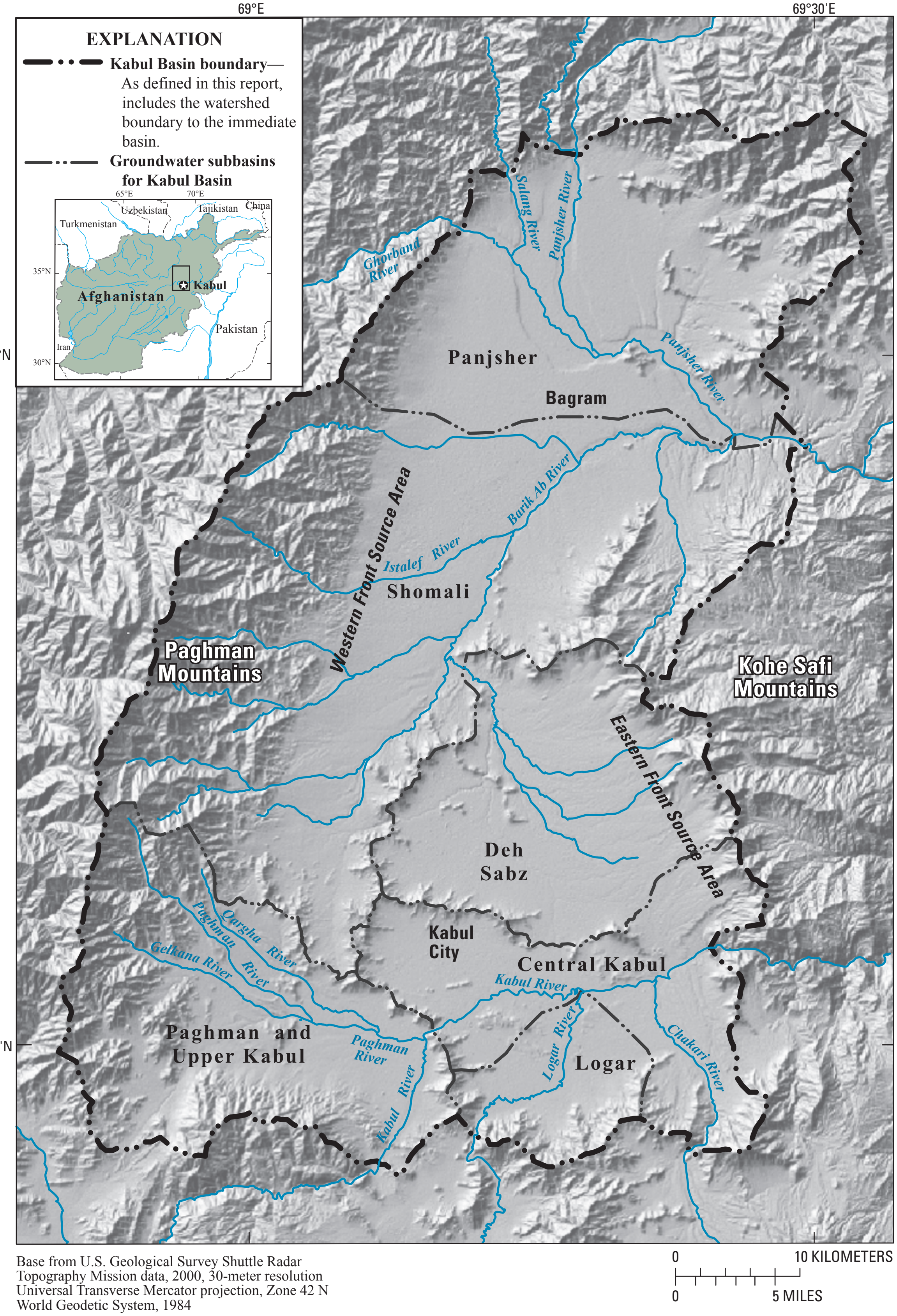


Figure 1. Study area of the Kabul Basin, Afghanistan, with major geographic features and subbasins.

Description of Study Area

The study area was the Kabul Basin, which is considered the geologic valley formed by the Paghman Mountains to the west and the Kohe Safi Mountains to the east (fig. 1). For this investigation, the Kabul Basin also includes the watershed boundary (fig. 1), which is the immediate drainage divide to the geologic valley. It excludes upland areas of the Ghorband, Salang, Panjsher, Kabul, Logar, and Chakari River basins outside the valley. Subbasins of the Kabul Basin are formed by interbasin ridges and river drainage divides and include Central Kabul, Paghman and Upper Kabul, Logar, Deh Sabz, Shomali, and Panjsher (fig. 1)[1].

Climate

Climate recordkeeping in Afghanistan was interrupted around 1980 as a consequence of war and civil strife. Few climatic data were available for Kabul; most records were not available until 2003 or later, and the record for most direct observations includes gaps of about 20 years or more. For example, temperature records were discontinued after 1991 and include a gap of about 12 years prior to recent network activation. Most other local climatic data-collection activities were discontinued in the early 1980s. Table 1 presents mean monthly temperature, precipitation, and estimated evapotranspiration for Kabul from historical records (Böckh, 1971). Average annual precipitation is low in the Kabul Basin; between 1957 and 1977 it was 330 mm/yr (Tunnermeir and Houben, 2003). Evaporation rates are high relative to annual total precipitation—approximately 1,600 mm/yr—and thus net groundwater recharge by precipitation in the Kabul Valley is generally near zero on an annual basis. Mean monthly precipitation (table 1) historically was highest in the spring (February to April, 58 to 84 mm), moderate in the late fall and winter months (November to January, 21 to 33 mm), and very low in the summer months (June to October, 1 to 5 mm). Regional evaporation has been calculated to range from 140 to 220 mm per month during the growing season (April to September). Snowpacks in the mountains surrounding Kabul Basin, particularly the Paghman Mountains (fig. 1), contribute to the water resources of the basin. Further discussion of the climate and snowpack is given in Appendix 1.

[1] In addition to the subbasins, two areas, the Western and Eastern Front Source Areas, are indicated on figure 1. These two areas differ with respect to recharge and chemical properties of groundwater and are discussed later in the report.

Geomorphology, Topography, and Geology

The landforms within the Kabul Basin are typical of an arid to semiarid, tectonically active region. All adjacent subbasins except for the Central Kabul and Logar subbasins and the Shomali and Panjsher subbasins are separated by prominent bedrock outcrops (fig. 2). The central plains of the subbasins are local depositional centers for sediments derived from the surrounding surficial deposits and bedrock outcrops. The central plains gently slope up to the adjacent mountains and hills to form piedmonts. Alluvial fans have developed on

Table 1. Mean monthly temperature, precipitation, and estimated evapotranspiration for Kabul, Afghanistan.

[mm, millimeters; ºC, degrees Celsius; –, not applicable or not calculated]

Month	Air temperature[1] 1957-1977 (ºC)	Air temperature[3] 1961-1991 (ºC)	Air temperature[3] 2003-2007 (ºC)	Evaporation[2] 1957-1963 (mm)	Precipitation[1] 1957-1977 (mm)	Precipitation[4] 2003-2006 (mm)
January	-2.5	-1.9	-0.9	50	33	43.4
February	-1	-0.3	4.9	70	58	47.8
March	6.5	6.6	9.5	120	64	79.1
April	12	13.3	15.2	140	84	31.1
May	17	17.8	19.5	180	25	28.9
June	22	23	23.3	210	1	0.8
July	24.5	25.1	25.9	220	5	6.5
August	23.5	24.4	24.9	210	1	0.6
September	19	20	21.4	150	2	5.4
October	12	13.7	14.6	130	2	1.8
November	5	12	7.8	80	21	29.2
December	-0.2	1.2	3.5	50	34	49.4
Annual average monthly	11	13	14	133	28	27
Annual total	–	–	–	1,610	330	330

[1]Approximated from graphs in Houben and Tunnermeier (2005).

[2]As reported in Böckh (1971).

[3]Food and Agriculture Organization, Afghanistan (2001).

[4]Fahim Zaheer, written comm., AGROMET, Afghanistan, 2008.

the flanks of the mountains surrounding the subbasins and on the interbasin ridges. The alluvial fans generally grade from coarse material near the source to finer material at the distal edges (Broshears and others, 2005). Physical weathering induced by extreme temperature fluctuations has produced pronounced breaks in slope at the edges of the subbasins (Houben and Tunnermeier, 2005). This continuing weathering process maintains the steep, rugged mountain slopes.

Geomorphology

The study area, which encompasses about 3,600 km^2, is primarily composed of Tertiary and Quaternary valley-fill sediments filling fault-bounded structural basins. Figure 2 presents a generalized representation of the surficial geology as delineated in the background investigations discussed below. Detailed analysis and compositional delineation of basin-fill sediments were developed in this study by applying decorrelation techniques on advanced spaceborne thermal emission and reflection radiometer (ASTER) imagery. ASTER data products that were processed and interpreted included visible-near-infrared region (VNIR) reflectance, short-wave-infrared region (SWIR) reflectance, and thermal-infrared (TIR) emissivity. A discussion of techniques used in the geomorphological analysis of basin-fill sediments is presented in Appendix 2.

Topography

The topography of the Kabul Basin is strongly influenced by regional and local tectonic activity and by fluvial processes. The basin is bounded by mountain ranges; the highest range, reaching 4,400 m in altitude, is the Paghman Mountains to the west of the study area. The Kohe Safi range to the east of the study area is as high as 3,000 m, and most of the range slopes out of the study area to the east. The interbasin ridges generally rise about 200 to 500 m above the adjacent valley floors. The central plains of the subbasins are generally flat, rising gradually to the surrounding bedrock outcrops. Altitudes of the central plains range from around 1,800 m in the Central Kabul and Logar subbasins to 2,200 m in the Paghman and Upper Kabul subbasin. Several ephemeral streams flow from the Paghman Mountains that border the Shomali area. Perennial and ephemeral stream channels have dissected the valley-fill sediments. Active stream channels are generally narrow and shallow, rarely exceeding 10 m in width and 5 m in depth. Some isolated topographic depressions in the Central Kabul and Logar subbasins act as catchments for surface-water runoff and are the sites of playa lakes or ephemeral marshes (Houben and Tunnermeier, 2005).

Geology

The Kabul Basin is part of the tectonically active Kabul block in the transpressional plate-boundary region of Afghanistan (Wheeler and others, 2005). A generalized geohydrologic section of the Kabul Basin is presented in figure 3 to illustrate the general structure and major geologic and hydrologic features. The western edge of the Kabul block is defined by the Paghman fault within the Chaman fault system (Ruleman and others, 2007). The Paghman fault trends north-northeast and is evident in the continuous fault scarp and piedmont alluvium along the western boundary of the Kabul Basin. The Paghman fault marks a transition from primarily left-lateral strike-slip movement on the Chaman fault to apparent left-lateral oblique-thrust faulting and dip-slip displacement on the Paghman fault. The eastern boundary of the Kabul Basin is marked by a few discontinuous linear fault scarps displaying normal dip-slip movement (Ruleman and others, 2007). Geomorphic evidence, such as left-lateral displacement of active stream channels, shows that movement on the Paghman fault has been sustained throughout much of Quaternary time (Ruleman and others, 2007).

The Kabul Basin can be described as a valley-fill basin-and-range setting where the valleys are filled with Quaternary and Tertiary sediments and rocks, and the ranges are composed of uplifted crystalline and sedimentary rocks (Bohannon and Turner, 2007; Lindsay and others, 2005). Quaternary sediments are typically less than 80 m thick in the valleys (Böckh, 1971). The underlying Tertiary sediments have been estimated to be as much as 800 m thick in the city of Kabul (Broshears and others, 2005; Japan International Cooperation Agency, 2007a; Houben and Tunnermeier, 2005) and may be more than 1,000 m thick in some areas of the valley (Böckh, 1971; John San Felipo, U.S. Geological Survey, written commun., 2007).

Most surficial geologic maps of the region are based on Afghan and Soviet mapping efforts (Abdullah and Chmyriov, 1977). The Quaternary and Tertiary sediments and rocks have been classified by Böckh, 1971; Bohannon and Turner, 2007; Houben and Tunnermeier, 2005; and Lindsay and others, 2005. Böckh (1971) divides the sediments into younger and older basin deposits. The younger deposits, the Reworked Loess Series, are described as reworked loess, gravel and sand, and talus. The gravel and sand were deposited mainly in the river channels. The Reworked Loess Series is as thick as 80 m in the Kabul Basin. The older deposits are the Lataband Series, the Kabul Series, and the Butkhak Series. The Lataband Series includes gravels and conglomerates ranging in thickness from several meters to several hundred meters. Houben and Tunnemeier (2005) describe the Lataband Formation as Quaternary terrace sediments of middle and younger Pleistocene age overlying conglomerates. In the central parts of the subbasins, the Kabul Series is described as at least 200 m thick. The series consists of marls, clays, siltstones, and fine-grained sandstones. Two boreholes drilled in the Logar subbasin penetrated 130 m of Kabul Series sediments. The Butkhak Series consists of the oldest known sedimentary deposits in the Kabul Basin, which are red silts, sandstones, clays, and conglomerates. The total thickness is thought to be more than 200 m.

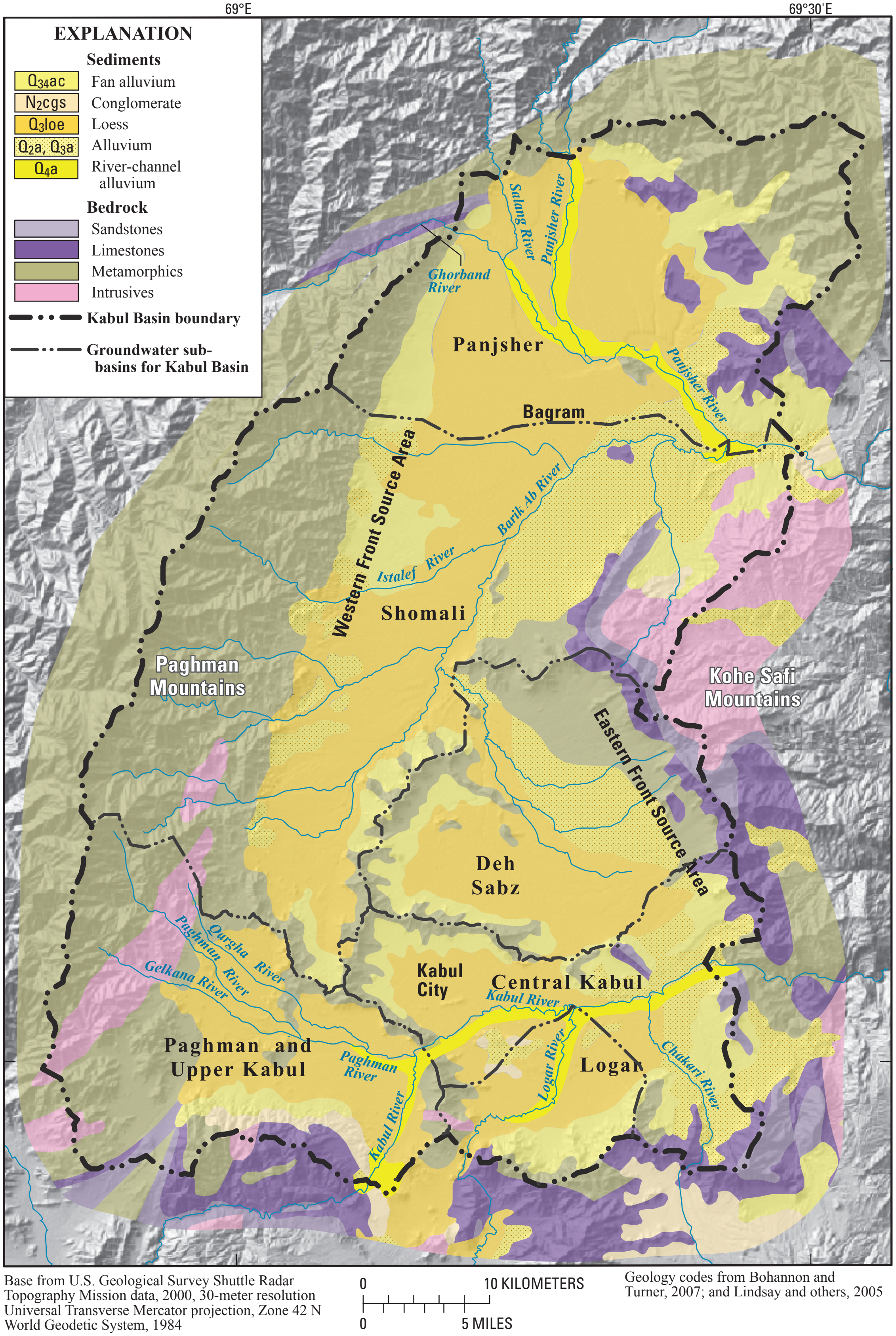


Figure 2. Generalized surficial geology and topography of the Kabul Basin, Afghanistan.

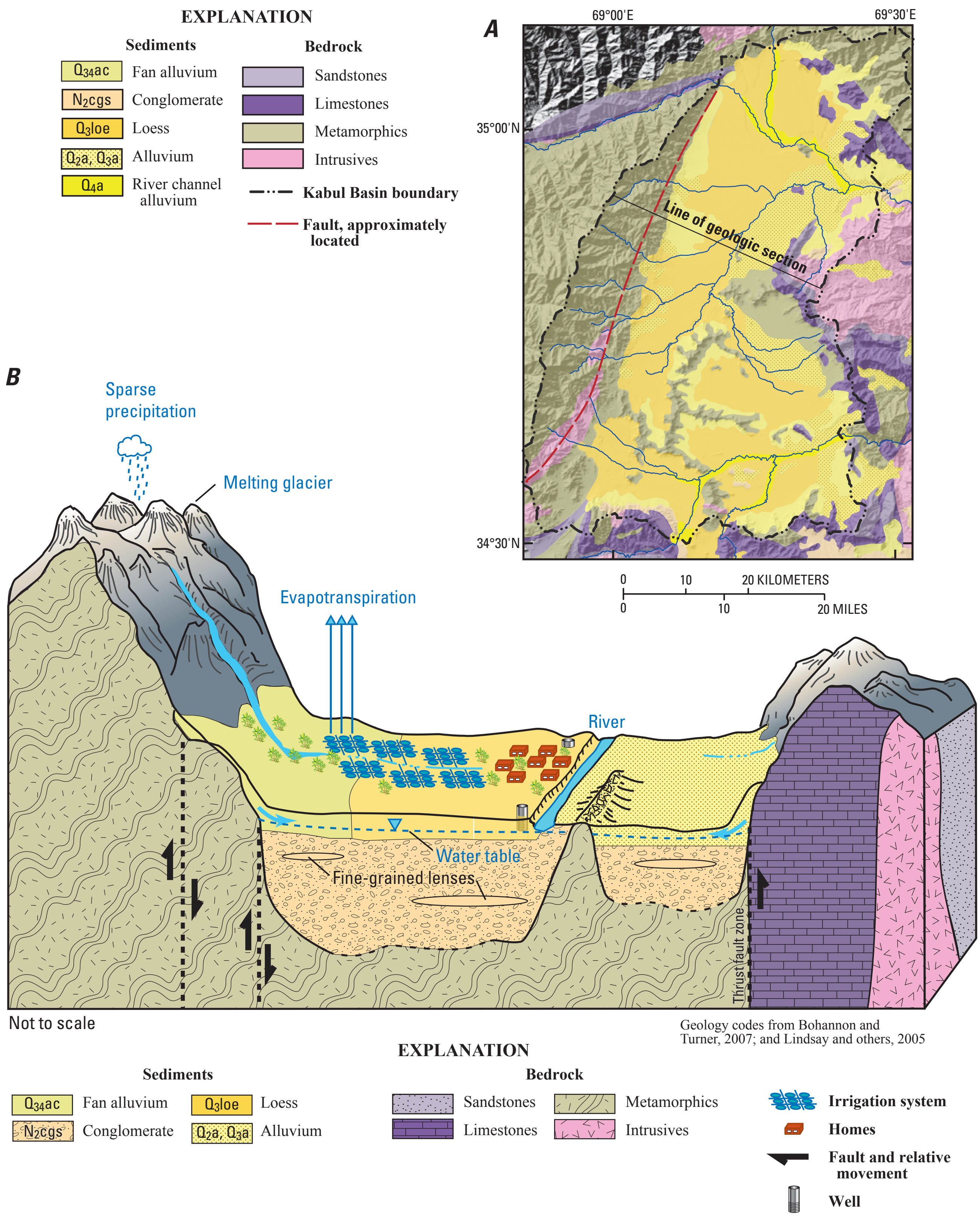


Figure 3. Planar view (A) and generalized hydrogeologic cross section (B) of the Kabul Basin, Afghanistan.

The geologic map of Bohannon and Turner (2007) shows Late Pleistocene loess in the centers of the subbasins, grading to Late Pleistocene conglomerate and sandstone and (or) Late Pleistocene-Holocene conglomerate and sandstone toward the bedrock outcrops. An exception to this transition is the western boundary, where the deposits at the contact between the alluvium-filled basins and the outcrops of the Paghman Mountains are Middle Pleistocene conglomerate and sandstone, Late Pleistocene loess, or Late Pleistocene-Holocene conglomerate and sandstone.

The surrounding mountains are primarily composed of Paleoproterozoic gneiss and Late Permian through Late Triassic sedimentary rocks (Bohannon and Turner, 2007). The interbasin ridges, composed of metamorphic core-complex rocks, are Paleoproterozoic gneiss. Basement rocks in the Kohe Safi, to the east of the Kabul Basin, are Paleoproterozoic gneiss and migmatite of the Sherdarwaza Series and low-grade schist and quartzite of the Walayati Series. The basement is overlain by Permian to Jurassic shelf or platform carbonate rocks of the Khengil Group (R.G. Bohannon, written commun., 2008). The Khengil and basement rocks are overthrust by schist mélange, which has been called the Kotagai Series, in the northern Kohe Safi range, and they are underthrust by mélange in Kabul River gorge (R.G. Bohannon, written commun., 2008). The mélange is tectonically overlain by large slabs of peridodite in the northern Kohe Safi. Early Cretaceous gabbro and monzonite intrusions are present in the Paghman Mountains. The composition of the rocks beneath the valley-fill sediments is not well known, but is probably similar to the predominant Sherdarwaza bedrock surrounding and within the Kabul Basin.

Hydrology

The Kabul Basin study area (fig. 1) is within the 25,500-km^2 Kabul River watershed. The number of major rivers flowing into the Kabul Basin undoubtedly contributed to the historical significance of the Kabul area. The headwaters of the Kabul River are west of the southwest corner of the study area (fig. 4). The Kabul River enters the study area from the south, flows north about 21 km to the city of Kabul, and then flows east, leaving the study area through a steeply cut valley in the Kohe Safi Mountains. The Paghman River flows eastward from the Paghman Mountains and enters the Kabul River in the city of Kabul near the point where the Kabul River begins to flow east. The Logar River, a large tributary to the Kabul River, enters the study area from the south through a steeply cut valley and flows northward for about 28 km. The Logar River enters the Kabul River at the eastern edge of the city of Kabul, about 17 km downstream of the mouth of Paghman River. The Chakari River enters the study area from the south, flows northward for about 35 km, and enters the Kabul River about 6 km downstream from the mouth of the Logar River. The Panjsher River enters the study area from the north through a steeply cut valley, flows south for about 24 km, southeast for about 33 km, and finally, following the regional geologic structure, south for about 38 km, joining the Kabul River 15 km east of the study area. The Ghorband River enters the study area from the northwest (fig. 4) through a steeply cut valley after flowing east for about 54 km through the Paghman Mountains. The Ghorband River enters the Panjsher River at the point where the Panjsher River turns and flows southeast. The Barik Ab River drains the central western flanks of the Paghman Mountains, flows north to the Panjsher River, and enters the Panjsher River about 16 km downstream of the mouth of the Ghorband River. General characteristics of the Kabul, Logar, Ghorband, and Panjsher River Basins are provided by Favre and Kamal (2004). Most water flows into and out of the Kabul Basin in the major rivers. Because of the limited extent of unconsolidated sediments where the major rivers enter or leave the study area at steeply cut valleys, groundwater inflow or outflow at the margins of the Kabul Basin (fig. 1) is likely to be much less than the groundwater flow in the subbasins.

Within and adjacent to the Kabul study area, 12 streamgages (fig. 4) were operated for various periods from 1959 until 1980. General characteristics of the subbasin watersheds, including mean runoff, and mean runoff per unit area, and periods of record, are provided in table 2. Historical streamflow records are available from data reports (German Water Economy Group of Afghanistan and Ministry of Agriculture of the Kingdom of Afghanistan, 1967; Democratic Republic of Afghanistan, 1977a and1977b; Democratic Republic of Afghanistan, 1981 and 1985).

Böckh (1971) collected discharge data at eight stations within the city of Kabul during the 1963 water year (a water year is defined as October 1 through September 30) and evaluated streamflow gains and losses to the underlying aquifer. Böckh's (1971) analysis, presented in Appendix 3, includes the locations of streamgages and annual and monthly discharges at the eight stations.

In 2005, three stations that record stage and discharge measurements were reestablished in the Kabul Basin study area: Logar River at Sang-i-Naweshta, Kabul River at Tang-i-Gharu (fig. 5), and Panjsher River at Shukhi. A limited analysis of this information is presented in this study. For the stations Logar River at Sang-i-Naweshta and the Kabul River at Tang-i-Gharu, either not enough discharge measurements were made to develop a discharge rating, and (or) the stage data are missing periods needed to compute daily streamflow for the complete year. For the station Panjsher River at Shukhi, stage and discharge data are available from March 21 through June 21, 2005, and from July 22, 2005 through September 30, 2006. Beginning in 2007, MEW is reestablishing a national streamflow-gaging network of about 163 stations. Data collected at these sites will be useful for future water-availability investigations.

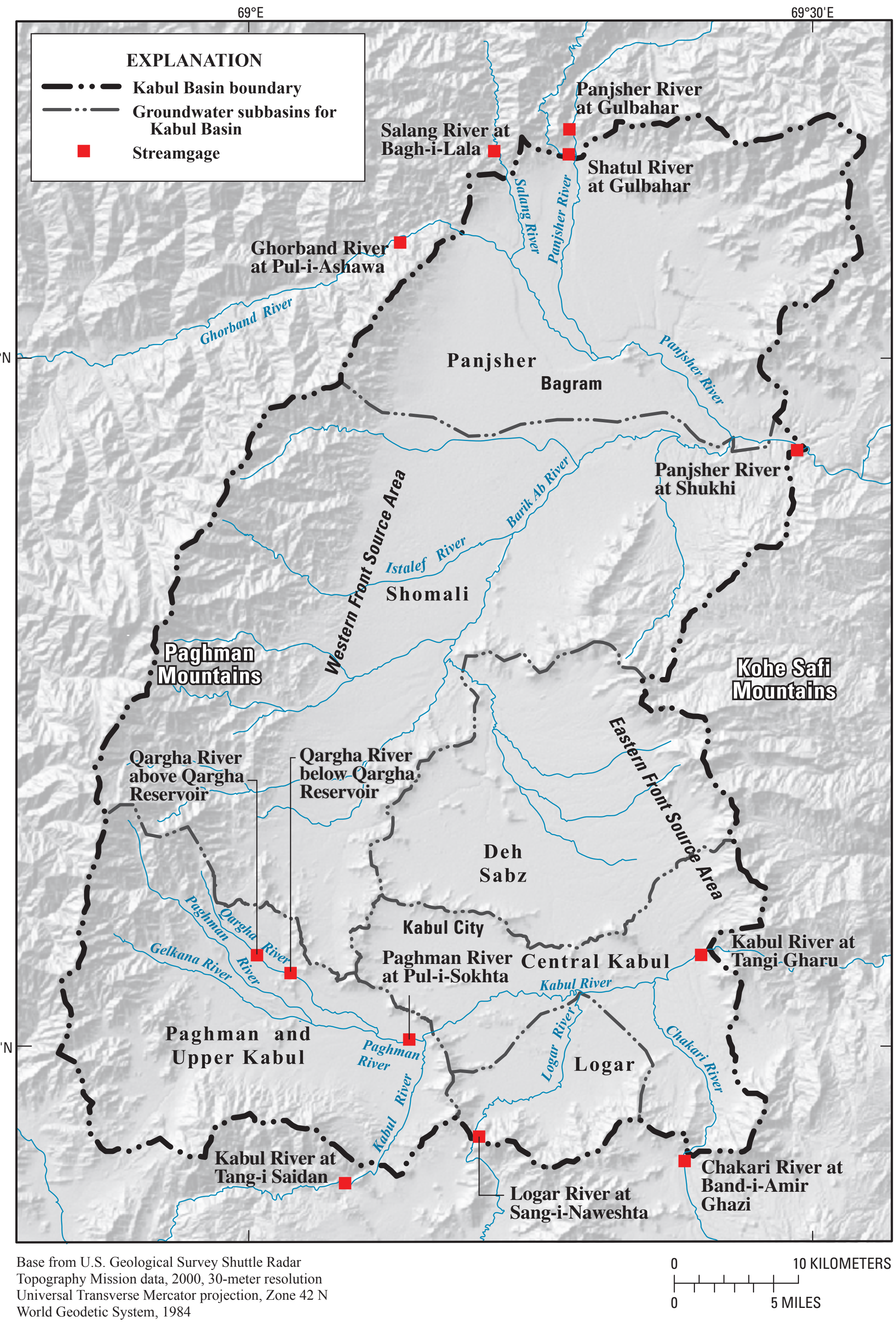


Figure 4. Locations of historical streamgages in the Kabul Basin, Afghanistan.

Table 2. Historical streamgages and general watershed characteristics in the Kabul Basin study area.

[Streamgages shown on figure 4; Latitude and longitude are given in decimal degrees. Runoff, in meters per second; km^2, square kilometers]

Streamgage	Latitude	Longitude	Mean annual runoff	Drainage[1] area, km^2	Runoff, km^2	Drainage[2] area, km^2	Runoff, km^2	Period of record
Kabul River at Tangi Saidan	34.40	69.08	4.05	1,625	0.002	1,663	0.002	10/01/1961 – 09/30/1980
Qargha River above Qargha Reservoir	34.57	69.02	0.33	70	0.005	20.79	0.016	04/16/1963 – 09/30/1980
Qargha River below Qargha Reservoir	34.55	69.03	0.22	115	0.002	43.21	0.005	10/01/1964 – 09/30/1980
Paghman River at Pul-i-Sokhta	34.50	69.13	0.72	500	0.001	424	0.002	03/01/1963 – 09/30/1980
Logar River at Sang-i-Naweshta	34.43	69.20	9.63	9,735	0.001	11,461	0.001	10/01/1961 – 09/30/1980
Chakari at Band-i-Amir Ghazi	34.42	69.38	0.31	395	0.001	302	0.001	05/26/1965 – 09/30/1980
Kabul River at Tang-i-Gharu	34.57	69.40	15.4	12,850	0.001	14,556	0.001	10/01/1959 – 09/30/1980
Panjsher River at Gulbahar	35.17	69.28	54.5	3,565	0.015	3,538	0.015	10/01/1959 – 09/30/1980
Shatul River at Gulahar	35.15	69.28	3.89	205	0.019	202	0.019	05/30/1967 – 03/06/1980
Ghorband River at Puli-Ashawa	35.08	69.13	23.1	4,020	0.006	4,032	0.006	10/01/1959 – 02/04/1980
Salang River at Bagh-i-Lala	35.15	69.22	10.1	485	0.021	435	0.023	10/01/1961 – 02/29/1980
Panjsher River at Shukhi	34.93	69.48	92.6	10,850	0.008	10,857	0.009	10/01/1966 – 09/30/1980

[1] Drainage area reported by previous studies.

[2] Drainage area calculated by this study.

Photograph by Vito J. Latkovich, USGS, retired, late 1960s

Photograph by M. Hanif Ashoor, Afghanistan Ministry of Energy and Water, 2007

Figure 5. Kabul River steamgage at Tang-i-Gharu. The top picture was taken in the late 1960s, and the bottom picture was taken in 2007. In the bottom picture, the old steamgage house is in the center of the picture, and the new steamgage is inside the building to the left.

Groundwater studies, including depth-to-water measurements, have been conducted in the Kabul Basin since 2001. The German Geological Survey (Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)) and the USGS have initiated programs in cooperation with Kabul University and the AGS, respectively. The BGR investigation focused on the shallow, mostly hand-pumped supply wells constructed by international relief agencies. Field work was conducted from 2003 until 2005.

Hydrologic Methods

A variety of data were collected, compiled from previous investigations, or obtained through remote sensing and provide background information for this investigation. Categories of data included climate, snowpack, glacier extents, surface-water flows, groundwater levels, water quality, chemical and isotopic information, and domestic and agricultural water use. Data were integrated through the development of a numerical groundwater-flow model to test the conceptual model of the hydrologic system.

Climate Analysis

The FAOCLIM 2.0 climate database (Food and Agriculture Organization, 2001) contains data from stations around the world, including Kabul, for which there are daily readings of minimum, maximum, and mean temperature from 1961 to 1991. Although continuous records are preferable, it is nonetheless useful to compare monthly mean temperatures from the last few years with monthly mean temperatures prior to the data gap. Monthly means were calculated from the previous record to characterize the annual temperature cycle for the period. Beginning in 2003, temperature and precipitation observations were once again recorded at a network of over 100 stations around the country, with one station at Kabul. Originally established by Food and Agriculture Organization (FAO), this agrometeorological network has been managed by the USGS since 2005. Data from this network were similarly used to calculate monthly mean values of daily mean temperature from 2003 to 2006. The two sets of monthly mean temperatures were then compared.

The more than 20-year gap in a complete record of direct climatic observations in Afghanistan coincides with a period of substantial warming observed at many locations around the world (Cayan and others, 2001; Christensen and others, 2007). For this reason, remotely sensed data and correlations of local climatic data with data collected in other areas of the world were used whenever possible in this investigation. Global data sets also provided indirect indications of how climate has varied in Afghanistan over the last 25 years or more. Normalized Difference Vegetation Index (NDVI) images prepared from National Oceanic and Atmospheric Administration (NOAA) advanced very high-resolution radiometer (AVHRR) data (Tucker and others, 2005) were used to examine trends in spring greenup from 1982 to 2002. The data set is global at 1.0-degree resolution and shows maximum values for monthly periods. For locations of interest, plots of monthly values through the year show the annual cycle of spring greenup and summer/fall senescence. Values over a three-by-three pixel area including Kabul (longitude 68°E–70°E, latitude 33°N–35°N) were spatially averaged to create a single 21-year time series. To characterize the early part of the period, monthly mean values for each month of 1982–1985 were calculated, and for the latter part of the period, monthly means for each month were calculated for 1999–2002. The shapes of the two resulting 12-month time series were compared to identify differences in the timing of spring greenup.

Precipitation estimates from satellite data were used as a key input to an energy-balance model for simulation of snowpack accumulation and depletion. Daily national grids of snow-water equivalents for five seasons (2002 through 2007) were developed for drainage areas above the Kabul River at Tang-i-Gharu and the Panjsher River at Shukhi streamgages. Daily values of total snow-water volume were simulated for the areas above each of the two stations for the five winter seasons. Further discussion of the total snow-water volume simulation is presented in appendix 1.

Surface Water

Information for the 12 streamgages (fig. 4) within and adjacent to the Kabul Basin, operated between 1959 and 1980 (table 2), were compiled from historical publications (German Water Economy Group of Afghanistan and Ministry of Agriculture of the Kingdom of Afghanistan, 1967; Democratic Republic of Afghanistan, 1977a and 1977b; Democratic Republic of Afghanistan, 1981 and 1985) and entered into the USGS National Water Information System (NWIS) to provide data-checking and analysis tools. General characteristics of the subbasin watersheds, including mean runoff, and mean runoff per unit area, and periods of record, were calculated and presented in table 2. Further discussion of the surface water methods is presented in Appendix 3.

Groundwater Levels

The AGS Hydrogeology Group, with assistance from the USGS, initiated a study that focused on deep wells, many of them municipal supply wells, in 2004. Since then, the study has operated a water-level-monitoring network in the Kabul Basin to continue the work begun in 2004 (Akbari and others, 2007). Sixty-nine wells in the Kabul Basin were selected for monthly monitoring (fig. 6). Water-level data were collected in most wells in the monitoring network from the late summer of 2004 until the present. Wells were selected from an inventory of existing wells and were chosen to provide spatial coverage and, to the extent possible, a range of depths below land surface. The AGS-USGS water-level studies in the Kabul Basin concentrated on deeper wells that ranged in depth from 4.9 to 30 m and were equipped with hand pumps. Depths to water below land surface ranged from less than 5 m to about 68 m; these depths corresponded to water-level altitudes ranging from 2,279 m above sea level (ASL) to 1,466 m ASL. Seasonal water-level fluctuations can be estimated from the hydrographs for static wells and ranged from less than 1 m to about 9 m from September 2005 through May 2006.

In the previous AGS-USGS study of the Kabul Basin, the area was subdivided into five subbasins to facilitate analysis of the water-level data from the water-level-monitoring network (Akbari and others, 2007). The original five subbasin areas represent drainage areas to tributaries (Deh Sabz, Paghman and Upper Kabul, and Shomali) or major rivers in the Kabul Basin (Central Kabul and Logar) (fig. 1). The current investigation extends northward to include a sixth subbasin, the Panjsher, which is formed by the Panjsher River within the Kabul Basin.

Water-Quality Sampling

The engineers from the AGS Hydrogeology Group also collected data on water quality at wells (fig. 6) in the Kabul Basin. A description of methods and the results of the water-quality investigations conducted from July through November 2004 are presented in Broshears and others (2005).

Prior to visiting field sites, training on the collection and processing of water samples for laboratory analysis was given to the Hydrogeology Group engineers by the USGS. The proper methods to be used for collecting and processing different types of water samples (including filtering, filling, acidifying, capping, and labeling) were demonstrated. The engineers were trained in the collection and processing of water samples to be analyzed for bacteria, cations and trace elements, major anions, and nitrate and nitrite. Training included the use of a 0.45-micrometer capsule filter for filtered acidified (FA) and filtered unacidified (FU) samples and the preservation of the FA samples by using polypropylene vials of Ultrex nitric acid. The engineers were trained in the collection of nitrate and nitrite samples in 11-mL vacuum tubes by first collecting a sample in a sterile cup and then transferring the sample to the vacuum tube. Bacterial samples (total coliform and *Escherichia coli (E. coli)*) were collected in sterile 100-mL containers for later processing and analysis.

Because of logistical and security concerns, it was not practical to filter samples in the field. Samples for chemical analysis (FA and FU) were collected in 2- or 4-L high-density plastic containers and transported to the AGS building for filtering and further processing. These samples were analyzed at the USGS National Water-Quality Laboratory (NWQL)[2] Lakewood, Colorado, USA, and at the USGS Water Chemistry Laboratory, Reston, Virginia, USA. The 11-mL vacuum tubes and 100-mL bacterial samples were kept chilled until they were processed and analyzed. Processing of the bacterial samples involved dissolving special bacterial nutrients in the 100-mL sample container and then pouring the sample into the incubation trays. The incubation trays were sealed and placed in the incubation oven for 24 hours. After 24 hours of incubation, the trays were removed, and the total coliform and *E. coli* counts were determined as the most probable number of colonies per 100-mL volume.

[2] A description of the analytical procedures used at the NWQL is available from http://nwql.usgs.gov/nwql.shtml.

Chemical and Isotopic Sampling

As a part of this investigation, chemical and isotopic groundwater samples were collected from May 2006 through June 2007 and surface-water samples from June 2006 through July 2007 for chemical and isotopic analysis. Chemical and isotopic measurements made on both types of samples included (1) the stable hydrogen and oxygen isotopic composition; (2) the major- and minor-element chemical composition (30 elements); (3) the dissolved-gas composition, including dissolved nitrogen, argon, carbon dioxide, oxygen, methane, helium, and the chlorofluorocarbons (CFCs) CFC-11, CFC-12, and CFC-113; and (4) the tritium content. The CFC composition of air samples was also determined. Sampling locations are shown on figure 6.

Samples were collected by AGS personnel following USGS protocols, as described in the previous section, and shipped by air freight to the USGS in Reston, Virginia. The water samples for tritium determination were then shipped to the USGS low-level tritium laboratory in Menlo Park, California, USA, for processing by electrolytic enrichment and liquid scintillation counting. All other water and air samples were analyzed in the laboratories of the USGS in Reston, Virginia. Water samples were chemically analyzed in the USGS Water Chemistry Laboratory in Reston, Virginia, by procedures that included inductively coupled plasma-optical atomic emission spectrometry (ICP-OES), inductively coupled plasma-mass spectrometry (ICP-MS), ion chromatography (IC), and alkalinity by an autotitration procedure. The stable hydrogen and oxygen isotopic compositions of water samples were determined at the USGS Stable Isotope Laboratory in Reston, Virginia. The stable hydrogen isotopic composition was analyzed by gaseous hydrogen equilibration (Coplen and others, 1991), and the oxygen isotopic composition was determined by the carbon dioxide-water equilibration technique of Epstein and Mayeda (1953; see http://isotopes.usgs.gov). The concentrations of CFCs were determined by gas chromatography with electron-capture detector (GC-ECD) procedures at the USGS Chlorofluorocarbon Laboratory, Reston, Virginia (see http://water.usgs.gov/lab/cfc). Concentrations of other dissolved and atmospheric gases were determined by gas chromatography procedures in the USGS Dissolved Gas Laboratory, Reston, Virginia (see http://water.usgs.gov/lab/cfc). Further details about the collection and analytical procedures for chemical and isotopic data are given in Appendix 4.

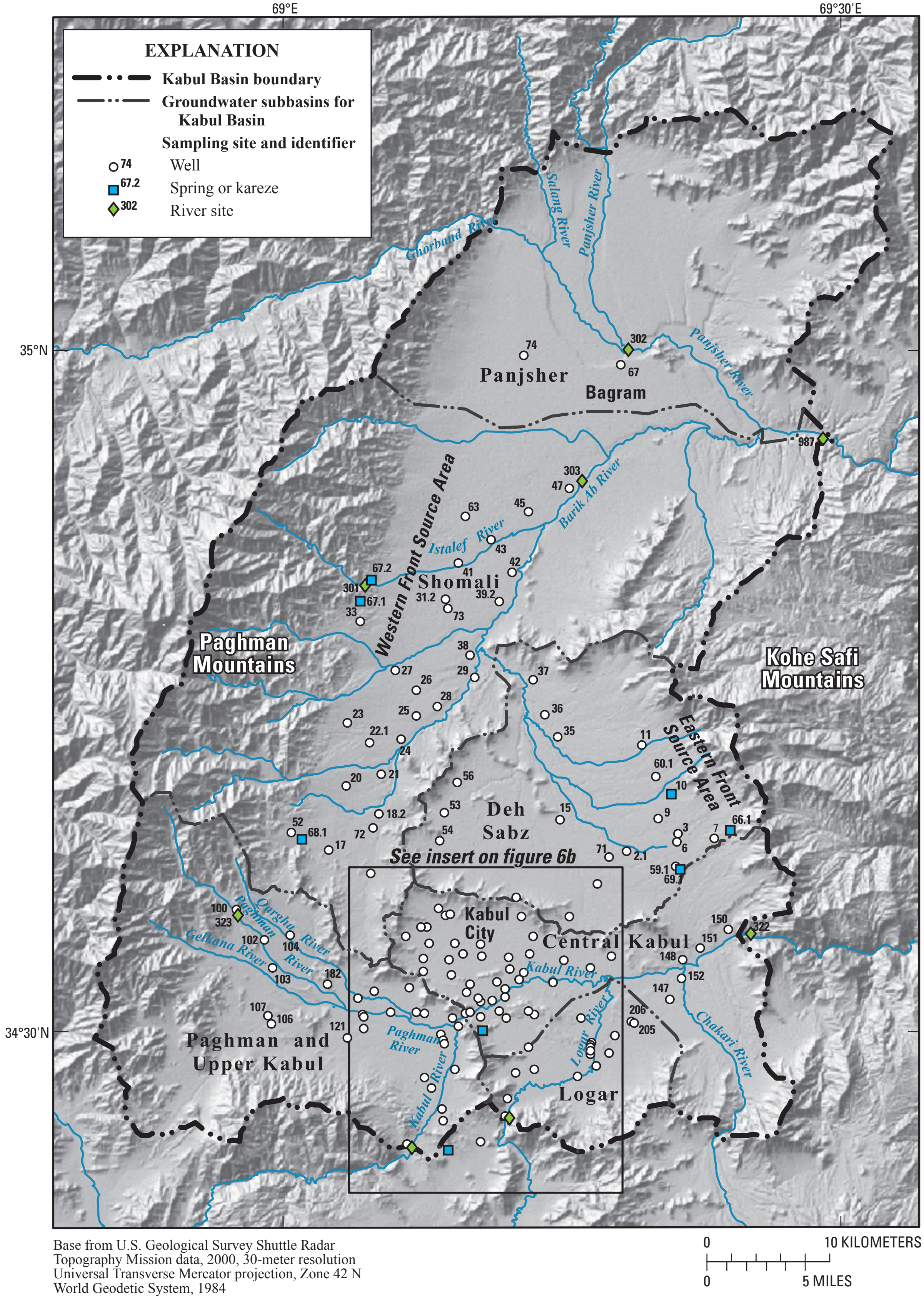
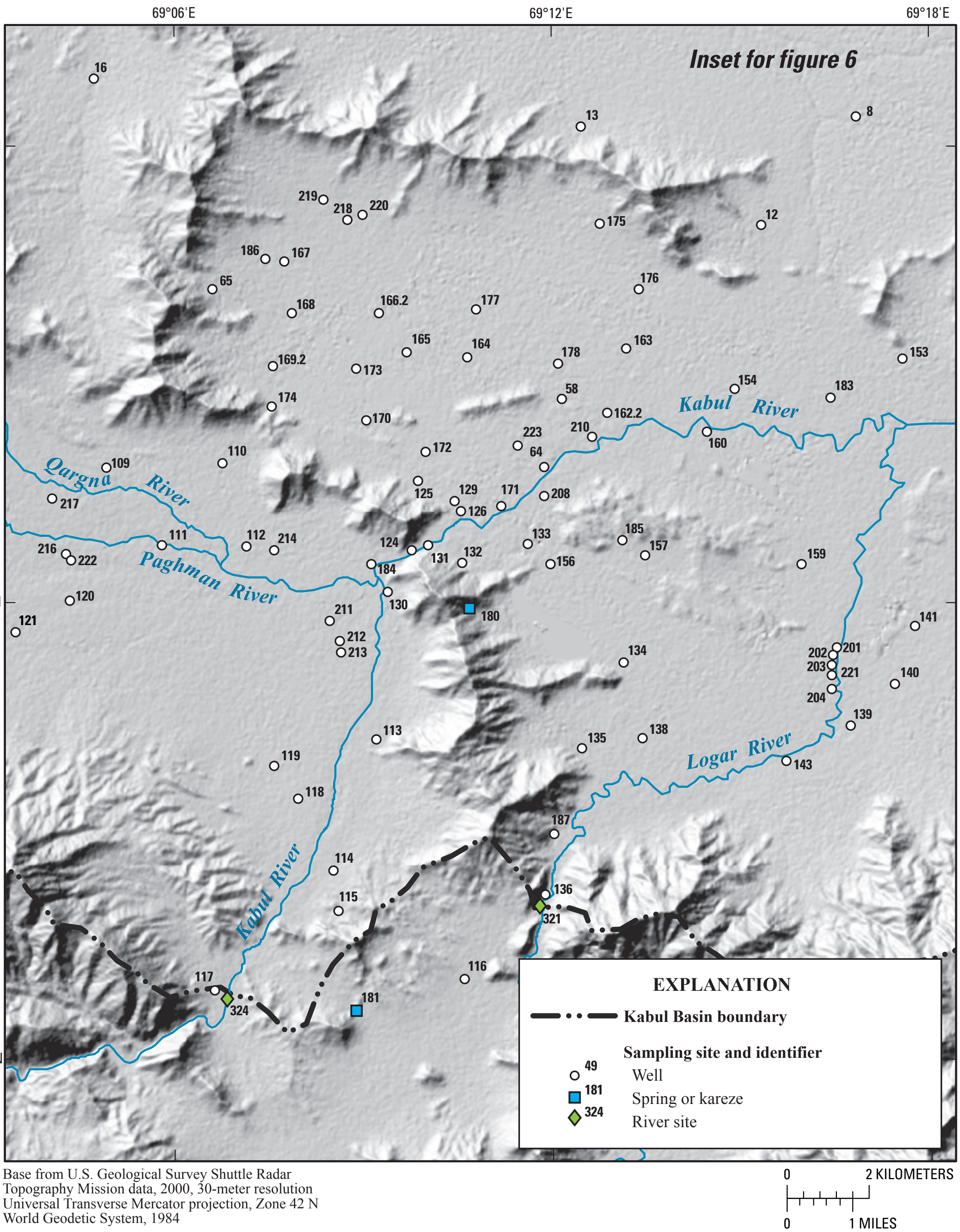


Figure 6. Locations of wells in the groundwater-level-monitoring network in the Kabul Basin, Afghanistan.



Base from U.S. Geological Survey Shuttle Radar Topography Mission data, 2000, 30-meter resolution
Universal Transverse Mercator projection, Zone 42 N
World Geodetic System, 1984

Figure 6. Continued.

Water Use

Water use in the Kabul Basin can be grouped into two major categories—combined municipal and domestic use, and agricultural irrigation. The amount of water used for industrial purposes is unknown but is probably much less than that used for other purposes. Water for municipal and domestic use is generally supplied by community or individual wells, which are concentrated in the more populated areas. Water use for agricultural purposes has been estimated to be at least an order of magnitude greater than that for domestic use (Uhl, 2006). Agricultural use is seasonal, generally from May through September, and is concentrated in the northern and western areas of the basin. Water is primarily supplied by irrigation canals from streams or karezes, which are a historical type of water-supply system common in the study area and throughout Afghanistan and other arid countries of the Middle East. A karez consists of a dug underground conduit that intersects the water table near the top of an alluvial fan and directs groundwater discharge laterally out to irrigated land at the base of the fan.

Municipal and Domestic

The city of Kabul operates municipal supply and distribution systems in parts of the city; however, limited information on municipal water systems was available for this study. The municipal systems are supplied primarily by groundwater from more than 40 supply wells, and secondarily by surface water obtained from the Qargha Reservoir in the upper Paghman River watershed. In rural areas, domestic water generally is supplied by shallow dug or driven wells, but also may be supplied by deeper wells, karezes, springs, or surface-water sources.

The per person rate of water use in the study area is not known and most likely differs considerably from rural to urban areas. Estimated per person water-use rates reported for Kabul include 40 L/d (Niard, 2007), 50 L/d (Afghanistan Ministry of Energy and Water, written commun., 2005), and 60 L/d in winter to 110 L/d in summer (Böckh, 1971). Estimated per person water use in rural areas is thought to be lower than previous estimates, generally about 20 to 30 L/d. In 2006, municipal groundwater withdrawals in the city of Kabul were reported to be approximately 40,000 m^3/d from a few pumping centers in the city (Mr. Djallazada, Ministry of Urban Development, oral commun., 2007). Low estimated rates of water use, such as 11 L/d by Uhl (2006), may be realistic for domestic use in the more rural areas; however, in rural areas individuals also provide water to livestock and small gardens, and the total per person use rate for both domestic and livestock uses might be close to rates for more urban areas. With increasing security and an improving standard of living, future per person water-use rates may be greater than current rates.

If the per person water-use rate is assumed to be 25 L/d (0.025 m^3/d), the Kabul municipal-supply system serves about one million people in the city. Shallow wells equipped with hand pumps supply local domestic water needs in many urban and rural areas throughout the Kabul Basin. The Ministry of Urban Development indicates that municipal groundwater withdrawals in the city of Kabul were expected to increase to 120,000 m^3/d in 2009 with the installation of additional planned wells. The total population in the Kabul Basin was estimated to be approximately 3.5 million in 2002 (Afghan Information Management System, written commun., 2006) with about 66 percent of the population (2.3 million) in the Kabul district (table 3) which includes the city of Kabul. The population is anticipated to increase by approximately 20 percent by the year 2012 (Mr. Rashid Fahkri, Central Statistics Office Afghanistan, written commun., 2007). At the time of this study (2007), population estimates were not available for the city of Kabul beyond 2012.

Between 1997 and 2005, the Danish Committee for Aid to Afghan Refugees (DACAAR) installed approximately 1,500 shallow wells (with a median depth of 22 m) in the Kabul Basin with about 1,000 of these wells in the three subbasins of the city of Kabul (Safi and Vijselaar, 2007). Of the DACAAR wells with status reported, about 25 percent in the city of Kabul were reported as dry or inoperative, whereas about 20 percent in the larger Kabul Basin were reported as dry or inoperative. Water levels have declined by about 10 m since 1982 in the city of Kabul's intermountain aquifers because of increased water use (Safi, 2005). Increasing water use has reduced groundwater levels, which in turn have led to dry wells. During recent droughts, more than 25 percent of shallow wells have gone dry (Safi, 2005).

Table 3. Population estimates for 2002, and estimated annual domestic water-use rates for provinces and districts in the Kabul Basin, Afghanistan.

[Population data, Afghanistan Information Management Services; km^2, square kilometers; L/d, liters per day; mL/yr, million liters per year]

Province	District[1]	Area (km^2)	2002 Population	Water use coefficient (L/d)	Water use (mL/yr)	Percent of total
Kabul	Istalef	375	39,709	30	435	0.9
Kabul	Qarabag	202	77,583	30	850	1.8
Kabul	Guldara	105	24,171	30	265	0.6
Kabul	Kalakan	85	32,695	30	358	0.8
Kabul	Dihsabz	48	43,270	30	474	1.0
Kabul	Sakardara	300	80,281	30	879	1.9
Kabul	Mir Baca Kot	41	55,139	30	604	1.3
Kabul	Paghman	358	117,615	30	1,288	2.8
Kabul	Kabul	375	2,306,125	40	33,669	72.0
Kabul	Bagrami	270	24,710	30	271	0.6
Kabul	Cahar Asyab	218	35,393	30	388	0.8
Kabul	Musayi	97	20,825	30	228	0.5
Kapisia	Kohistan	94	99,164	30	1,086	2.3
Kapisia	Kohband	151	19,423	30	213	0.5
Kapisia	Nijrab	571	94,632	30	1,036	2.2
Kapisia	Mahmud Raqi	195	58,376	30	639	1.4
Parwan	Jabalus Saraj	171	101,861	30	1,115	2.4
Parwan	Caharikar	268	156,461	30	1,713	3.7
Parwan	Bagram	306	97,761	30	1,070	2.3
Parwan	Kohi Safi	661	16,833	30	184	0.4
	Total	2,474	3,502,027		46,765	100

[1] District name may differ from usage elsewhere in the report.

Agricultural

A simplified surface-energy balance (SSEB) method (Senay and others, 2007) was used to estimate agricultural water use in the Kabul Basin. The method uses agricultural models and remotely sensed images of the land-surface temperature to produce 1-km gridded estimates of evapotranspiration at 8-day intervals during the growing season (Appendix 5). Evapotranspiration (ET) is the combined transport of water from the land surface to the atmosphere as a consequence of plant transpiration and direct evaporation of surface water and near-surface soil moisture. Agricultural water use occurs primarily in three areas of the Kabul Basin (fig. 7), and irrigation is almost entirely supplied by karezes and streamflow diversions. In the northern part of the study area, irrigation is supported by diversions from the Panjsher River and its tributaries. Agriculture in the Shomali Plain in the middle of the study area is supported by flows from the Paghman Mountains. Agriculture in the southern part of the study area is supported by streamflow diversions from the Kabul River and its tributaries. Although many wells have recently been installed in the Kabul Basin, the use of groundwater for irrigation is still likely to be low because of prohibitive fuel costs.

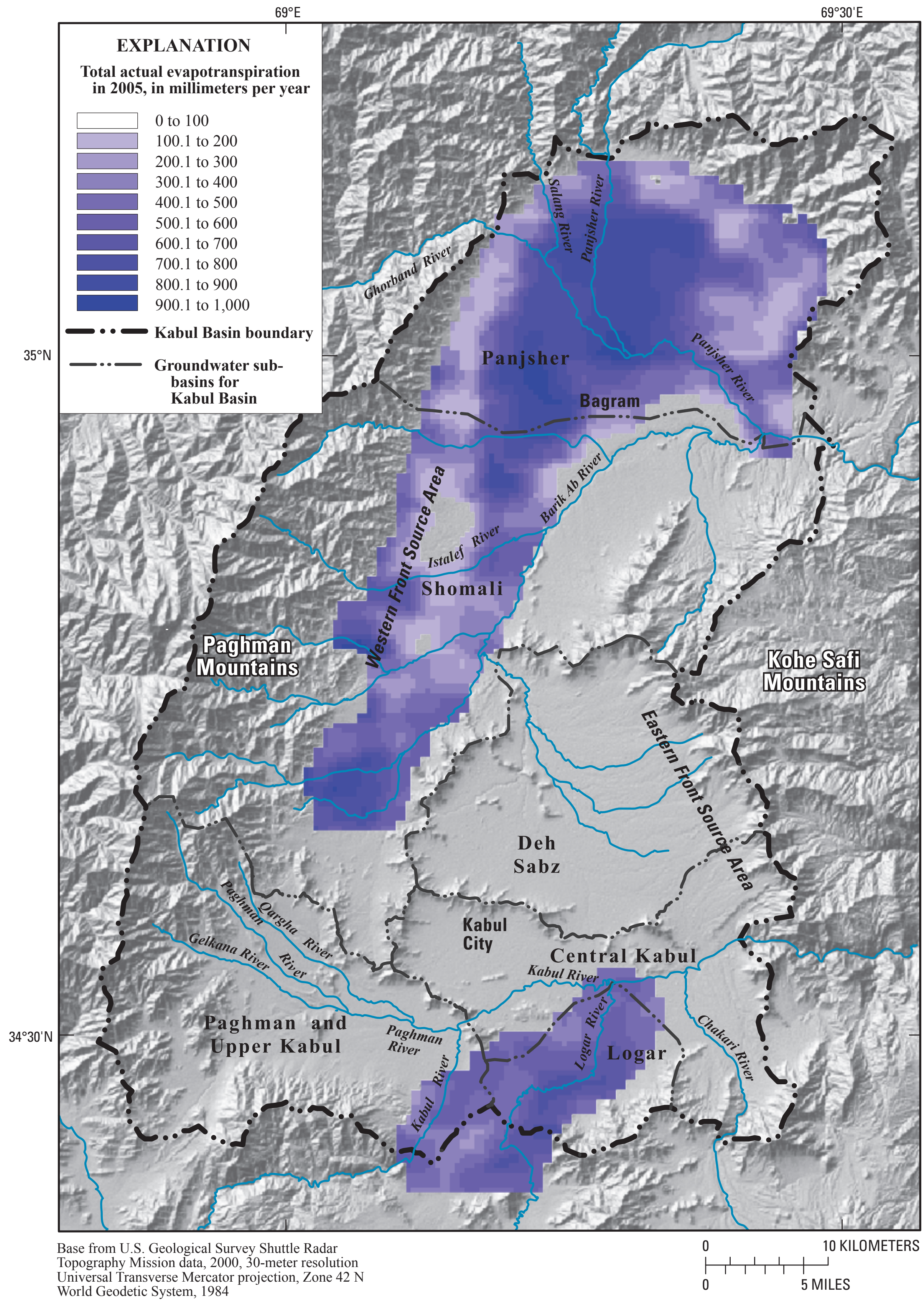


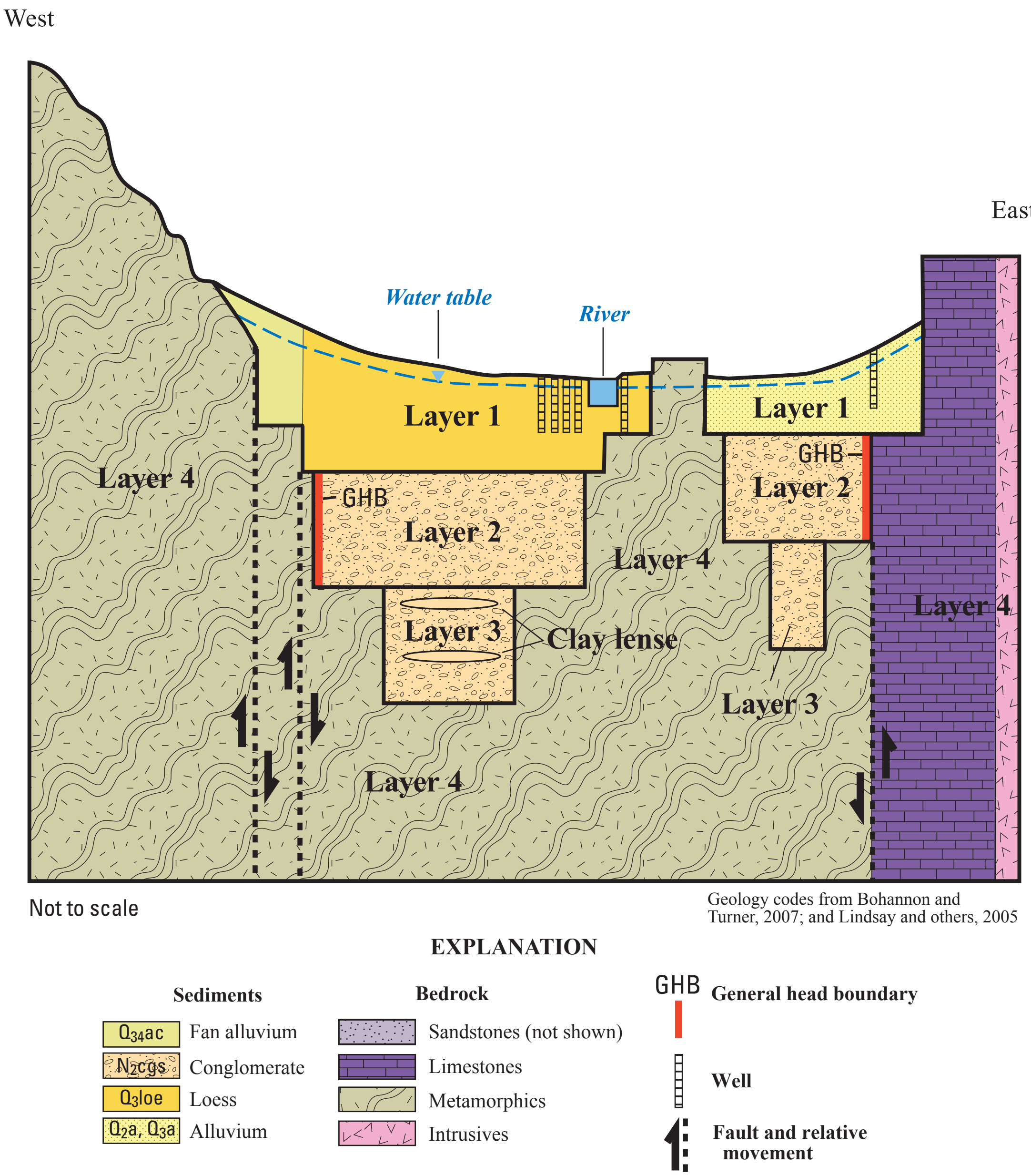
Figure 7. Areas of estimated actual evapotranspiration (AET) in the Kabul Basin, Afghanistan.

Groundwater-Flow Simulation and Conceptual Model

An integrated analysis of historical data, recently collected data, and results from hydrogeologic investigations was provided by testing conceptual models of the Kabul Basin with a numerical groundwater-flow model. The steady-state model was designed to assess the regional groundwater-flow system, including flow in the shallow Quaternary aquifers and in the underlying Neogene aquifer (differentiated into an upper and lower Neogene aquifer) in the Kabul Basin. The finite-difference groundwater-flow model MODFLOW 2000 (Harbaugh and others, 2000; Hill and others, 2000) was used in this study. The model developed for this investigation incorporates findings from the various components of this investigation and assesses several hypotheses, or scenarios, regarding water availability in the Kabul Basin. With this approach, all components of the hydrologic system were assessed jointly to provide an integrated assessment of the geohydrologic system. The particle-tracking program MODPATH (Pollack, 1994) was used to simulate groundwater-flow paths to withdrawal wells in the upper Neogene aquifer to help identify sources of groundwater in the study area.

The steady-state model was developed and evaluated with historical and recent data as available. Surface-water-discharge and groundwater-level data are the primary types of hydrologic data used to calibrate a groundwater-flow model, but in this study the available data were from different decades. The model was considered a conceptual model, as opposed to a calibrated model, because some components of the hydrologic system were poorly understood or were based on data from different time periods—in particular, properties of the Neogene aquifer, the magnitude of subsurface hillside inflows into the basin, and the magnitude of irrigation leakage into the aquifer system. Although the model was conceptual, it provided a basis for assessing components of the groundwater-flow system. Future uses of this model may include the assessment of water-resources-management strategies.

The lithologic groups in the Kabul Basin (Bohannon and Turner, 2007; Lindsay and others, 2005) were regrouped by major hydrologic characteristics (fig. 2), primarily hydraulic conductivity, to form general geohydrologic zones (fig. 8). The model area was subdivided into a grid of 400-by-400-m cells and the grid was aligned with the primary axis of the Kabul Basin (fig. 1). The lateral model boundary coincided with the watershed boundary for the Kabul Basin (fig. 3), consisting of the major drainage divides that form the mountain ridges defining the basin (figs. 3, 8). The model was divided vertically into four layers (fig. 8). Layer 1 represented Quaternary sediments (figs. 2, 8), typically less than 80 m thick in the basin; layers 2 and 3, each 500 m thick, represented the underlying Tertiary (Neogene) semiconsolidated bedrock in the subbasins and included bedrock at the perimeters of the subbasins; and layer 4 was 1,000 m thick and represented the underlying bedrock at depth. Although Neogene aquifer properties are not well known, layer 2 was designed to simulate groundwater flow in the upper Neogene, and layer 3, groundwater flow in the lower Neogene. Flows into and out of the model area included major streams (fig. 4), areal recharge, head-dependent boundaries at selected hillsides, leakage in irrigated areas (fig. 7), and domestic water use. Model development and the simulation of the components of groundwater flow and streamflow interactions in the Kabul Basin aquifer system are described further in Appendix 6.



The west and east side of the section coincides with the watershed boundary for the Kabul Basin shown on figure 3.

Figure 8. Generalized hydrogeologic representation, including numerical-model layers, of the Kabul Basin, Afghanistan.

Hydroclimatologic, Geologic, and Geochemical Characteristics of the Kabul Basin

Results of climatic, hydrologic, geologic, water quality, and geochemical analyses were evaluated in this study to assess water resources in the Kabul Basin. These analyses, which were based on historical, remotely sensed, and recently collected data, were incorporated individually or jointly into a groundwater-flow simulation model to provide a more complete description of water resources.

Climate Trends

Past (1961–1991) and recent (2003–2007) mean monthly temperatures are presented in figure 9A. The graphs indicate a general warming trend throughout the year between the earlier and recent periods. The strongest warming effects are +5°C in February and +3°C in March (fig. 9B). Vegetation trends indicate that the large increase in February temperatures is likely to have been consistent through the 1992–2002 period without temperature records; the rate of change has been about 1°C for every five years since the early 1960s (fig. 9C).

The trace of mean monthly vegetation index (NDVI) is greater from December through April for 1999–2002 (fig. 10); this difference suggests that winters were milder and springs began earlier than during the 1982–1985 period. Earlier senescence is also suggested by the more rapid drop of the NDVI curve during June and July for 1999–2002. March is the month with strongest upward trend in NDVI over the period of record (fig. 10). The observed shift in the annual NDVI pattern is consistent with the warming suggested by the temperature curves in figures 9A–C. Increased February temperatures are followed by an earlier flush of green on the landscape in March. Comparisons of historical (fig. 4) and recent streamflows at the Shukhi River streamgage (discussed in Comparison of 2006 Water-Year Streamflow to Historical Streamflow) also reveal this trend, although no conclusions can be made based on the short periods of record. Streamflow analysis (presented in Streamflow Statistics) indicates that in 2006, May was the month of peak runoff, compared with June during the 1960s and 1970s. Although these analyses based on short records do not prove a warming trend, the similar trends in the temperature, NDVI, and streamflow data suggest that climate in the Kabul Basin has been warming in recent decades.

These findings are consistent with those reported for the western United States, which has extensive areas that are climatically and topographically similar to the Kabul region. Earlier spring runoff has been documented in snowmelt-dominated rivers since the late 1940s (Stewart and others, 2004), as has earlier blooming of lilac and honeysuckle bushes, a measure of the onset of spring (Cayan and others, 2001). Westerling and others (2006) documented a concomitant increase in wildfire activity that they attributed to climatic warming and earlier spring. Closer to the study area, Prasad and Singh (2007) have noted a pronounced reduction in the extent of glaciers in the western Himalayan region shared by China, India, and Pakistan, on the basis of a qualitative comparison of USGS Landsat imagery from 1972, 1989, and 2000.

Trends of this kind are expected to continue throughout the 21st century in mountainous regions (Christensen and others, 2007), including the western U.S. and central Asia. Stewart and others (2004) foresee a one-month advance in the timing of spring runoff in the western U.S. under a continuation of the current trend in greenhouse-gas emissions. Such a change is expected to reduce the storage efficiency of reservoirs by requiring earlier flood-protection releases, while at the same time lengthening the characteristic summer dry season. Westerling and others (2006) foresee an increased frequency of large wildfires during these longer and more intense periods of summer drought. Christensen and others (2004) used hydrologic modeling to estimate the effects of continuing climate changes on Colorado River flows and projected runoff reductions of 17 percent, reservoir-storage reductions of up to 40 percent, and associated reductions in hydropower production.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) described 21st-century projections of climate under various scenarios of greenhouse-gas emissions. Twenty-three models with hundreds of simulations were analyzed, with the multimodel mean response being the most commonly evaluated statistic. The global pattern of climate change indicated by the results suggests broad-scale warming, especially over continental land masses and in northern polar regions (Meehl and others, 2007). Multimodel ensembles suggest dramatic decreases in the number of frost days, increases in the number of heat waves, and longer growing seasons for most Northern Hemisphere land masses. An increase in surface temperatures in mountainous regions around the world is predicted fairly consistently by the models. In temperate mountainous regions, the snowpack may respond rapidly to small increases in temperature. These changes could reduce the snowpack thickness and affect the timing and magnitude of snowmelt because as warming increases, a greater fraction of precipitation will occur as rainfall rather than snow. For every degree (Celsius) increase in temperature, the altitude of the snow line could increase by an average of about 150 m (Christensen and others, 2007). Simulations for the Alps suggest that a 4°C increase in surface temperature (consistent with expectations for Afghanistan) would be associated with a 50-percent reduction in snow duration at 2,000 m (Christensen and others, 2007). The implications of future climate change for water resources in the Kabul Basin may be cause for concern. Modeling by Milly and others (2005) projected a decrease in runoff of 20 to 30 percent for Afghanistan; the IPCC Working Group 2 on Impacts, Adaptation, and Vulnerability ranked the water resources of central Asia and west Asia as “highly vulnerable” at a “very high” level of confidence (Cruz and others, 2007).

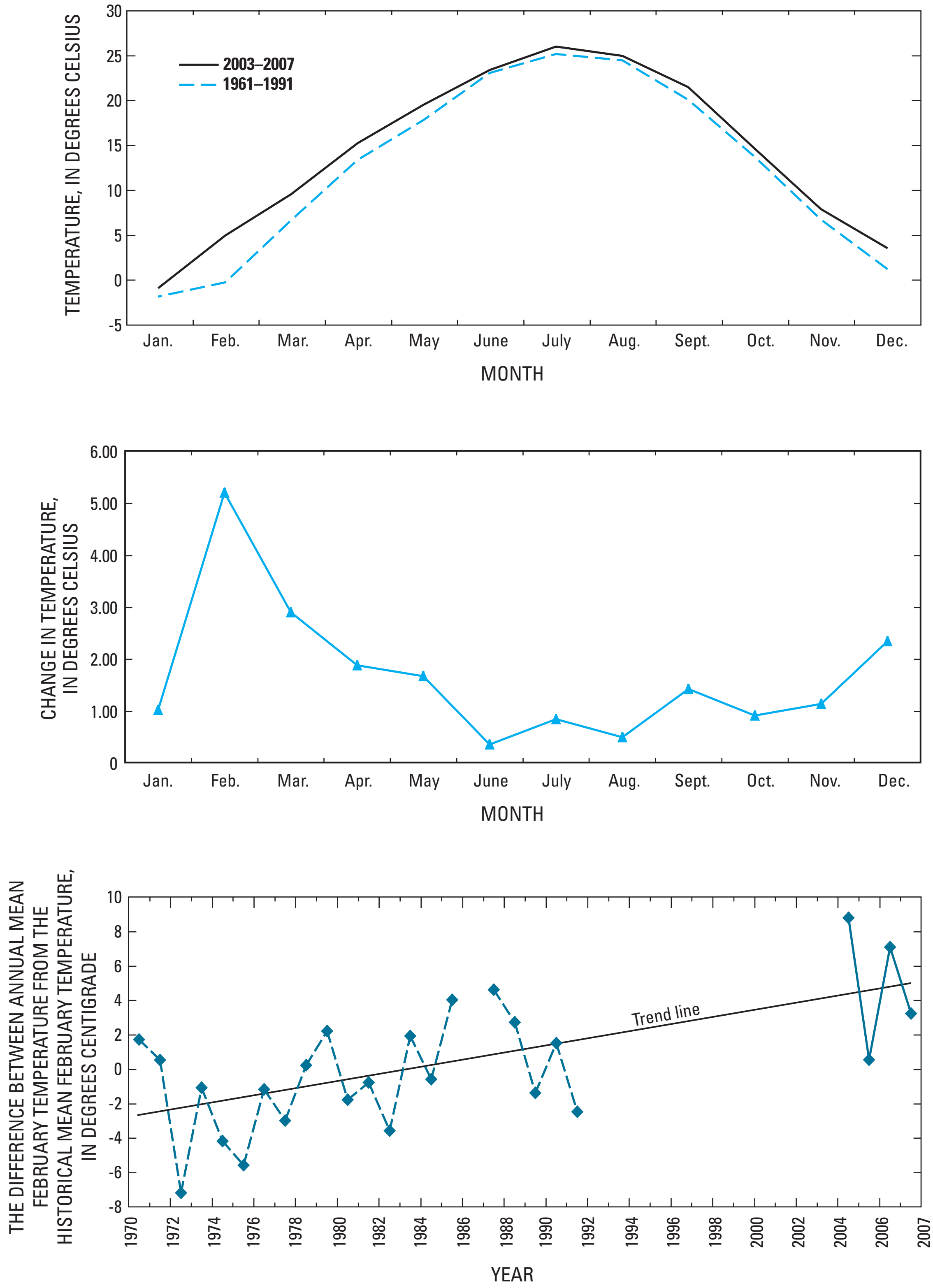


Figure 9. (A) Annual graphs of mean monthly temperatures for the 1961–1991 and 2003–2007 periods; (B) increases in mean monthly temperatures from 1961–1991 to 2003–2007; and (C) warming trend in the mean February temperature for 1970–2006 at Kabul, Afghanistan.

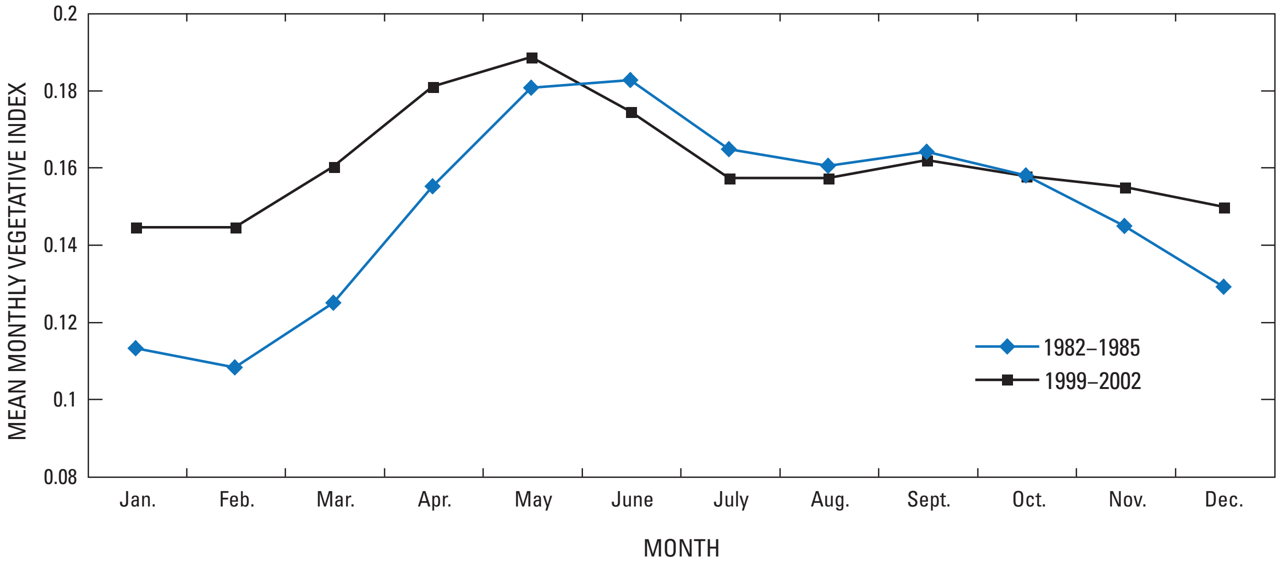


Figure 10. The mean monthly vegetative index (NDVI), or greenness, for 1982–1985 and 1999–2002, for the Kabul Basin, Afghanistan.

Geomorphology and Composition of Basin-Fill Sediments

Analysis of ASTER imagery (figs. 11 and 12) shows that quartz, feldspars, smectite clays, carbonates, and ferric iron of both alluvial and hardpan origin are the most widespread components of Kabul Basin sediments. The fine-grained components of these sediments are windblown dusts, called desert loess, which may form aquitards in the basin. Mafic and ferrous-iron-bearing minerals such as olivine, biotite, pyroxene, and amphiboles are largely destroyed during the process of weathering and subsequent erosion, and their exposures are confined to bedrock and talus deposits in close proximity to their bedrock source areas. Because silica-, aluminum-, carbonate- and ferric-iron-bearing minerals are mostly residual and do not readily remain in solution, nonresidual components of minerals derived from weathering (for example, Na^+ and K^+) are more soluble and thus are expected to play a major role in the groundwater chemistry of the basin. Notably, no other evaporite minerals or efflorescent salts with diagnostic spectral absorption features were abundant enough to be mapped by using either the ASTER VNIR-SWIR data (Crowley, 1993) or TIR data (Crowley and Hook, 1996); the most common of these minerals are gypsum and trona, which are characteristic of $Na\text{-}SO_4\text{-}Cl$ and $Na\text{-}CO_3\text{-}Cl$ brines, respectively (Crowley, 1991, 1993). Halite is also a common evaporite mineral which can be indicative of either lacustrine brines (Eugster and Hardie, 1978; Eugster, 1980) or irrigation-induced salinized soils (Dehaan and Taylor, 2002). Halite is difficult to map by spectral remote-sensing methods unless it is either wet (Crowley, 1991, 1993), rough (Chapman and others, 1989; Crowley and Hook, 1996), or promotes the growth of saline-resistant vegetation (Dehaan and Taylor, 2002). Typically, these minerals form in hydrologically closed basins, usually with groundwater and (or) stream-sustained saline lakes (Eugster and Hardie, 1978; Eugster, 1980). The Kabul Basin can be considered an open basin and does not satisfy the conditions necessary to form brines at the surface and ultimately to precipitate these evaporitic and efflorescent minerals. Further information about geomorphology and composition is given in Appendix 7.

Surface Water

Streamflow in the Kabul study area is extremely variable seasonally and annually as well as spatially. More than half of total annual streamflow occurs in the spring as the result of snowmelt. Two types of floods occur in the Kabul study area. The spring flood is the result of several factors, including snow and rain on snow during spring snowmelt. The less common type of flood is caused by rains during late spring, summer, and fall. Occasionally, monsoons extend into Afghanistan from the Indian Subcontinent and cause summer rainstorms. Long periods of no flow occur on most of the smaller rivers, and occasionally no-flow periods occur on the larger rivers.

Streamflow Statistics

Selected streamflow statistics were computed for the 12 historical streamgages in the study area (fig. 4). All streamflow statistics are based on the periods of record listed in table 2. Two sets of drainage areas are presented to facilitate comparisons of the data: drainage areas listed in previous data reports, and drainage areas computed for this report on the basis of the latest available maps and geographic information system (GIS) software.

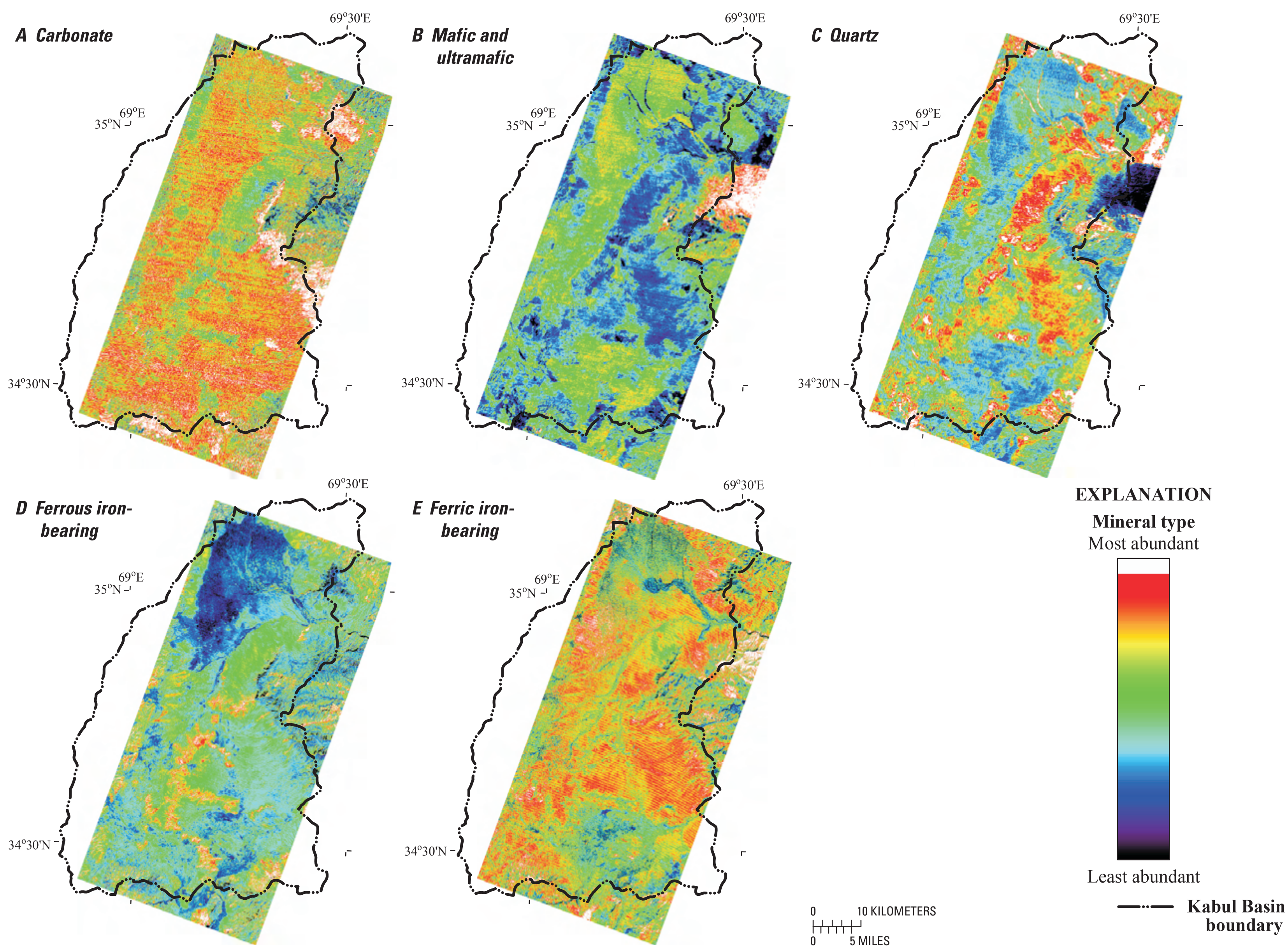


Figure 11. ASTER analysis of relative abundance of mineral groups containing (A) carbonate, (B) mafic and ultramafic minerals, (C) quartz, (D) ferrous iron, and (E) ferric iron in the Kabul Basin, Afghanistan.

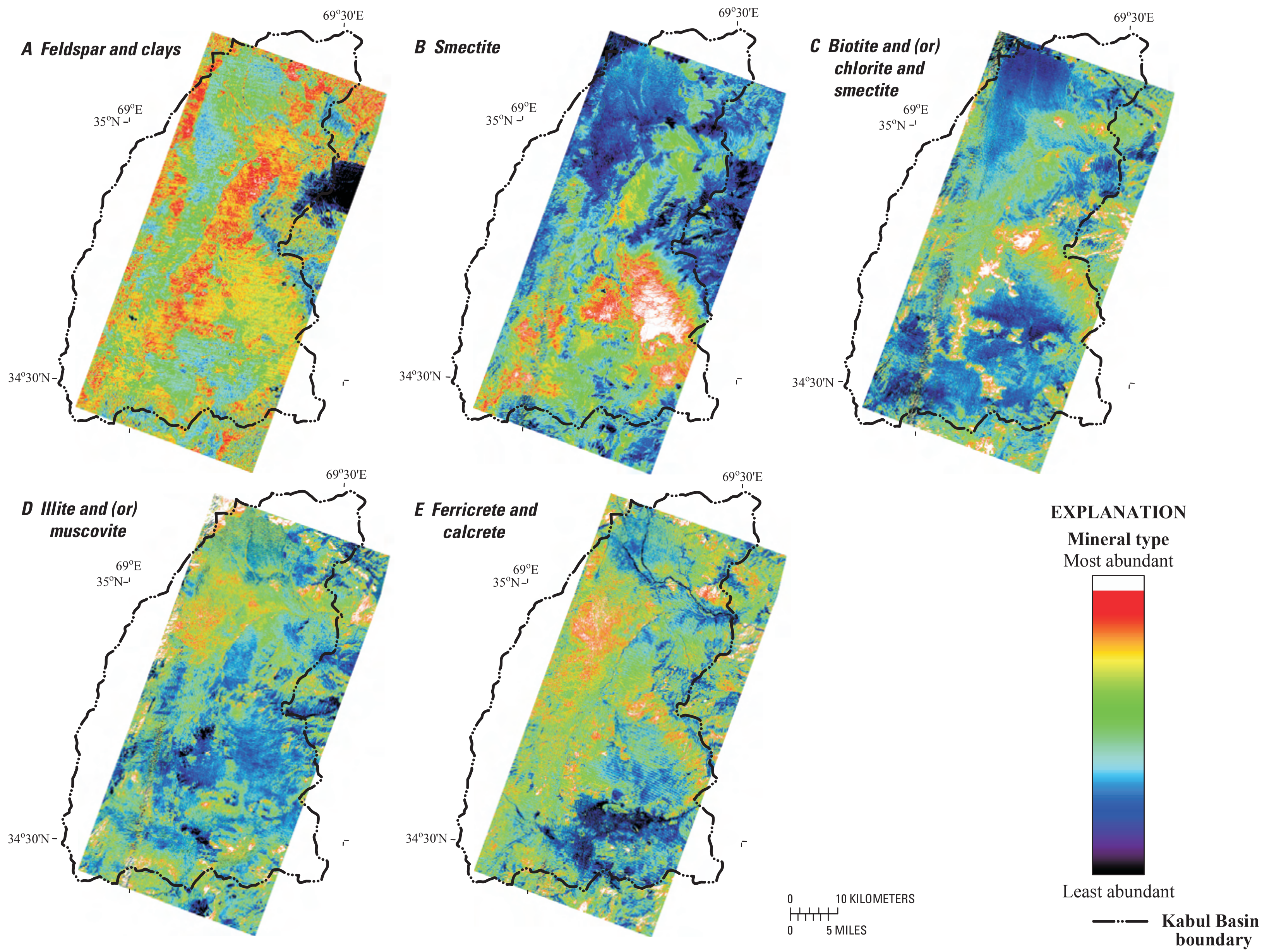


Figure 12. ASTER analysis of relative abundance of mineral groups containing (A) feldspar and clays, (B) smectite clays, (C) biotite and (or) chlorite and smectite, (D) illite and (or) muscovite, and (E) ferricrete and calcrete minerals in the Kabul Basin, Afghanistan.

Statistics presented for each streamgage include the maximum, minimum, and mean monthly discharges (fig. 13). Monthly mean values were calculated as the average of the daily values for one month for one specific year; months for which all daily values were not available were not included in the calculation of statistics. The maximum monthly mean discharge is the maximum of all the monthly mean values for a specific month during a specified period of years. Similarly, the minimum monthly mean discharge is the minimum of all the monthly mean values for a specific month during a specified period of years. The mean monthly discharge values are the means of the monthly mean discharges for each month during the respective periods of record for the stations.

The spatial variability of runoff in the Kabul study area is shown in figure 13. The streamgages on rivers in the southern portion of the study area (Kabul River at Tang-i-Saidan, Qargha River above Qargha Reservoir, Paghman River at Pul-i-Sokhta, Logar River at Sang-i-Naweshta, and Kabul River at Tang-i-Gharu) have recorded the highest monthly runoff values during April and a large variability in the mean monthly values for April and May. The flows at Qargha River below Qargha Reservoir and Chakari River at Band-i-Amir Ghazi are exceptions because the stations are below dams, and the monthly flows reflect reservoir releases. The runoff from the southern part of the study area is generally from the melting of the snow cover on the eastern slopes of the Paghman Mountains to the west and the northern slopes of the Dasht-i-Nawur Mountains to the south. The stations on rivers in the northern portion of the study area (Panjsher River at Gulbahar, Shatul River at Gulbahar, Ghorband River at Pul-i-Ashawa, Salang River at Bagh-i-Lala, and Panjsher River at Shukhi) recorded the highest monthly runoff values during June and a large range between minimum to maximum monthly values for May, June, and July (fig. 13). The runoff from the northern part of the study area is mainly from melting of the snow cover and glaciers from the southern slopes of the Hindu Kush Mountains outside and north of the study area in eastern and central Afghanistan. In 2007, glaciers covered about 66 km^2 of the Panjsher River drainage area, but there are no glaciers in the drainage area of the Kabul River that flows into the study area. The Hindu Kush Mountains are much higher than the Paghman or Dasht-i-Nawur Mountains, which have no glaciers. Therefore, more snow accumulates in the Hindu Kush Mountains, and it melts about 2 months later. The larger snow accumulation results in an average annual runoff per square kilometer of 0.020 m^3/s for the northern stations compared to 0.004 m^3/s for the southern station

Flow duration is computed by tabulating the number of daily discharge values within a range bounded by preselected limits, computing the frequency of occurrence of values within each range, and interpolating discharge values for the occurrences. Flow durations for the 12 stations are shown in figure 14.

Extensive and highly permeable aquifers or glaciers in the headwaters of streams generate a relatively stable supply of water, resulting in a relative stable flow. These streams also tend to have large recession indices. The recession index is the time it takes for streamflow discharge to decrease across one log cycle of a flow-duration curve plotted on a semilog graph with time. Conversely, streams that do not have a stable supply of water or lose flow as they cross highly permeable aquifers, for example, streamflow in the Kabul River (fig. 15), provide a less reliable supply of water, and tend to have small recession indexes. The indices for the stations Qargha River above Qargha Reservoir, Panjsher River at Gulbahar, Ghorband River at Pul-i-Ashawa, Salang River at Bagh-i-Lala, and Panjsher River at Shukhi are relatively high, indicating a more stable water supply; the water supply to the other stations with lower recession indices is less reliable. For station Panjsher River at Shukhi, the discharge of about 255.4 m^3/s was exceeded about 10 percent of the time and the discharge of about 26.3 m^3/s about 90 percent of the time (fig. 14). Conversely, for station Kabul River at Tang-i-Gharu, the discharge of 32.9 m^3/s was exceeded about 10 percent of the time and the discharge of 0.19 m^3/s about 90 percent of the time. Additional streamflow statistics and their descriptions are presented in Appendix 8.

Comparison of 2006 Water-Year Streamflow to Historical Streamflows

Of the records for the three streamgages that were reestablished in 2005 in the Kabul study area, only the Panjsher River at Shukhi station had available daily streamflow data. For this reason, the 2006 water year (October 1, 2006 to September 30, 2007) for Panjsher River at Shukhi is used for comparison to historical flows. Monthly mean discharges for the 2006 water year for Panjsher River at Shukhi were compared to historical mean monthly flows (fig. 16) from October 1, 1966, through September 30, 1980. The monthly means for the 2006 water year are within 25 percent of the medians for the historical period for October, November, December, January, February, March, August, and September. The monthly mean for April is 27 percent lower, May is 80 percent higher, June is 36 percent lower, and July is 54 percent lower than the respective mean monthly flows for the historical period. The monthly means for April, June, and July 2006 are above the respective historical minimums for those months; however, the monthly mean for May 2006 is above the historical maximum for May. Because most of the streamflow passes this station during these four months, any increase or decrease in flows during these months is critical and affects water supplies, irrigation, and hydroelectric-power generation. The peak runoff during water year 2006 occurred a month earlier (May) than normal (June). The annual mean for 2006 is 8 percent less than the historical mean annual flow.

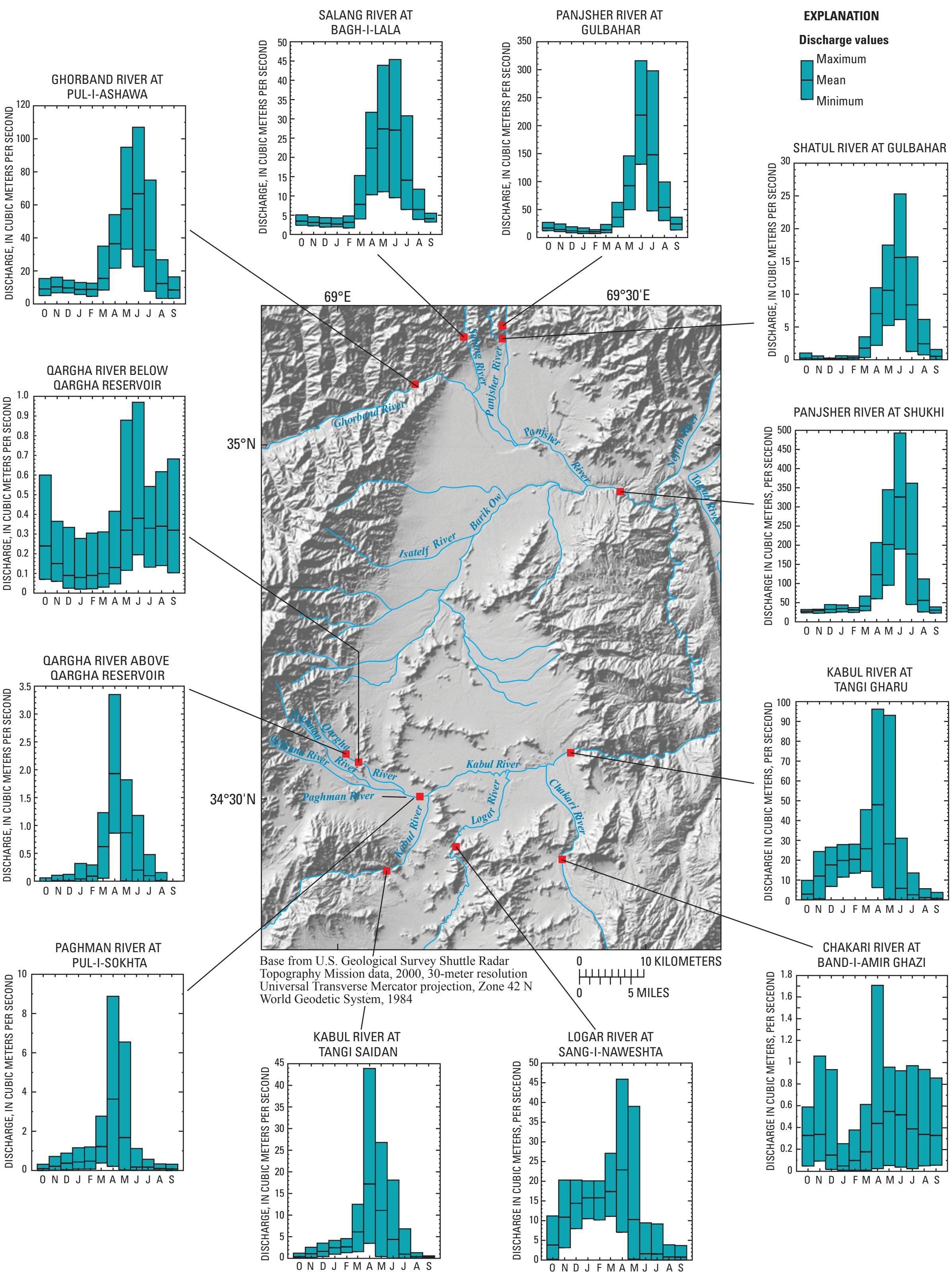


Figure 13. Maximum, minimum, and mean monthly discharges for the periods of record at 12 streamgages in the Kabul study area.

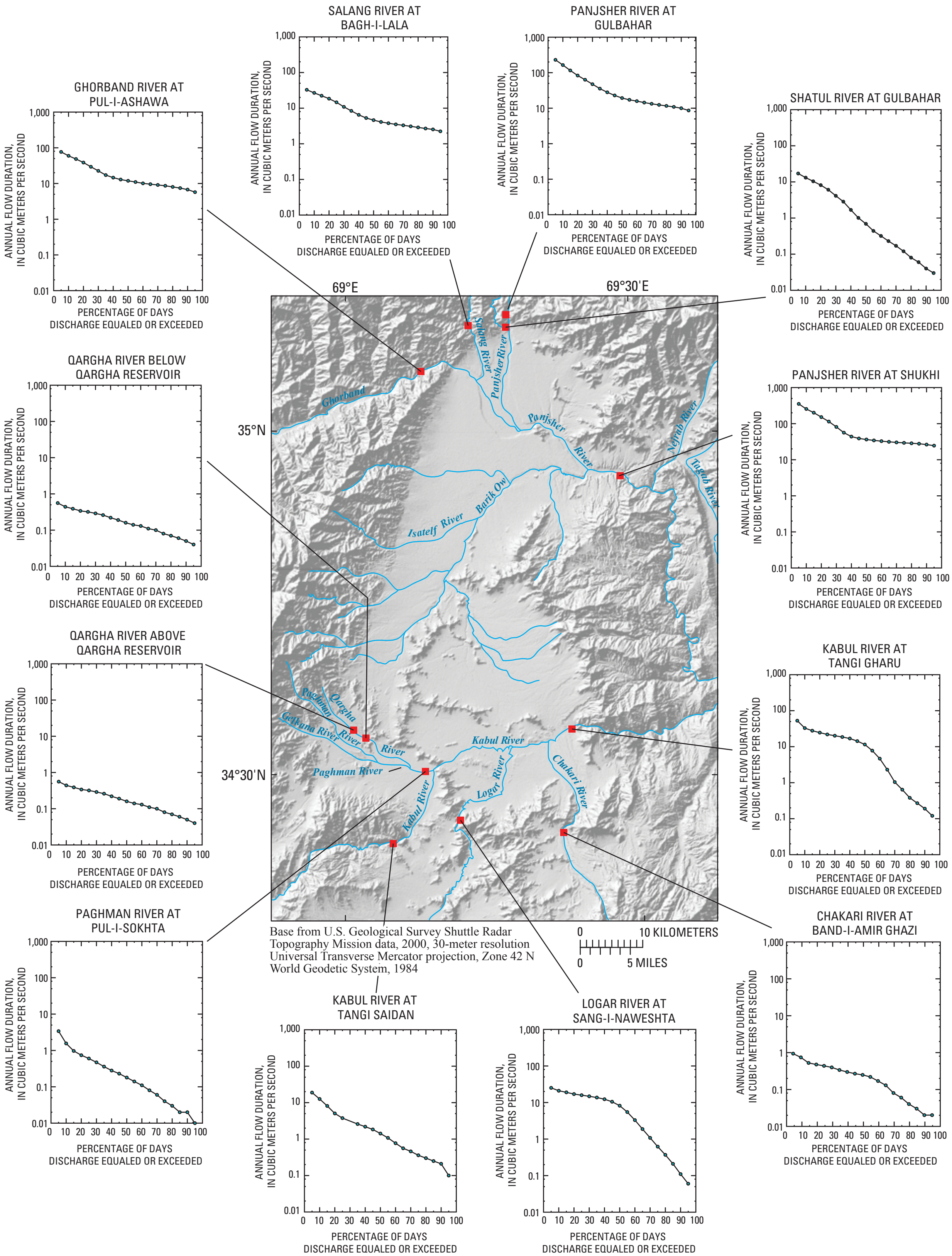


Figure 14. Annual streamflow durations for the periods of record at streamgages in the Kabul study area.

Figure 15. Streamflow in the Kabul River during low-flow conditions in August 2007, Kabul, Afghanistan. Photograph by M. Hanif Ashoor, Afghanistan Ministry of Energy and Water, summer 2007.

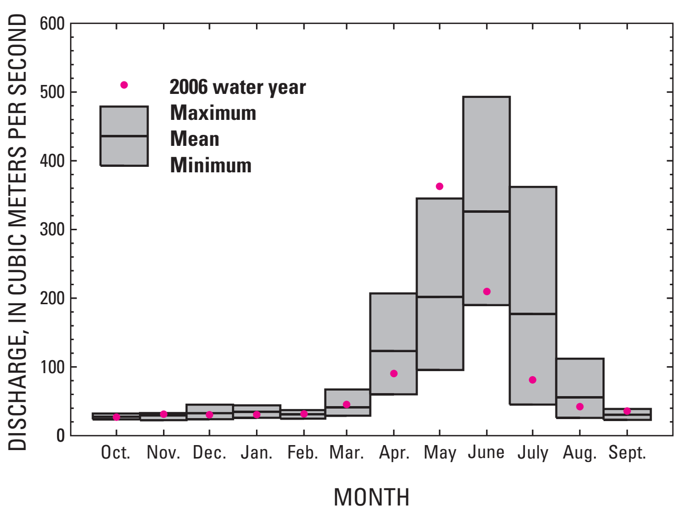


Figure 16. Comparison of the 2006 water-year monthly mean discharges with historical mean monthly discharges for the streamgage Panjsher River at Shukhi.

The 2006 water-year flows for Panjsher River at Shukhi should be a reasonable representation of the flows at the other historical streamgages in the northern part of the study area. The 2006 flows in the southern rivers cannot be assumed to be similar to the 2006 flows in the Panjsher River, because the precipitation and temperatures in the southern part of the study area are not necessarily related to those in the northern part of the study area. Unfortunately, the streamflow data for the rivers in the southern part of the study area is insufficient to determine the relative flows for 2005 or 2006. From general observation and discussion of the flows with Hanif Ashoor (Ministry of Energy and Water, oral comm., 2006) the streamflows in the vicinity of the city of Kabul are reported to have been zero or intermittent during May 2006. What little flows there were in the rivers upstream of the city of Kabul were being diverted for irrigation, an activity that exacerbates these low-flow conditions.

Groundwater

Groundwater in the Kabul Basin occurs in the surficial sedimentary (Quaternary) aquifers in the bottom of the basin or subbasins, the semiconsolidated Neogene aquifer sediments, and, to a lesser extent, the sedimentary and fractured metamorphic and crystalline bedrock of the mountains and interbasin ridges in the Kabul Basin. The primary groundwater resource used in the Kabul Basin is the surficial aquifer consisting of unconsolidated Quaternary sediments. Groundwater in the semiconsolidated Neogene aquifer sediments currently (2007) has little use and is presently being investigated for future use. Few wells have been completed in the underlying bedrock aquifers and, as a result, this aquifer is relatively unused; however this aquifer contributes water from upland areas to the overlying sedimentary aquifers.

Groundwater Levels

Groundwater levels in the Kabul Basin have fallen dramatically as a result of below-normal precipitation since about 1998. The mean annual precipitation from 1956 to 1983 was 312 mm (World Meteorological Organization, 2004). In 2001, only 175 mm of precipitation was reported for Kabul (International Water Management Institute, 2002). The below-normal precipitation has continued with the exceptions of only the years 2004–2005 and 2006–2007, when it was near normal in the Kabul Basin. Banks and Soldal (2002) reported declines of 4–6 m in the water table in Kabul during the drought period of the last 3–4 years (1998 to 2002) and of up to 10 m in some areas. They further state that the largest declines are probably a result of the effects of withdrawals superimposed upon climatic trends. The water level at the BGR project house in Kabul has declined from 2–3 m below land surface in 1965 to 9.5 m in 2004 (Houben and Tunnemeier, 2005), a drop of 6–7 m in 40 years. Weekly water-level measurements in DACAAR well no. 2 were collected from October 2003 until December 2005 by BGR investigators (Danish Committee for Aid to Afghan Refugees, 2007). The hydrograph for this well indicates that groundwater is recharged in the spring and that the water level has dropped by about 0.4 m from the maxima in July 2004 and May 2005. Comparing water-table contours measured by the 1965 German Geological Mission (Houben and Tunnemeier, 2005) to those reported by Broshears and others (2005) for Central Kabul, it is evident that water levels have dropped from 1,794–1,791 m ASL to 1,785–1,780 m ASL in about 40 years. Recent (2007) water levels indicate that groundwater levels are rising in response to lessening of the early 2000s drought, for example, well 116 in the Logar subbasin (fig. 17); however, water levels are declining in other areas of the Kabul Basin, for example, in well 167 in the Central Kabul subbasin, most likely in response to increasing withdrawals.

Broshears and others (2005) present a water-table map showing generalized directions of groundwater flow for five subbasins of the Kabul Basin; the map was based on AGS water-level data collected from July 2004 through November 2004. A simulated water-table surface for the Kabul Basin, including the Panjsher River subbasin, is presented in the Conceptual Groundwater Flow Simulation section of this report. The general direction of groundwater flow follows the regional topography and the direction of surface-water flow. Akbari and others (2007) present further analysis based on data from the AGS water-level network through March 2007 and selected water-level hydrographs by subbasin. Water-table altitudes in the study area range from 2,279 m ASL in the southwest Paghman and Upper Kabul subbasin to 1,466 m ASL in the northern part of the Shomali area. In Central Kabul subbasin, water-table altitudes range from 1,785 to 1,775 m ASL. The depth to groundwater along most stream channels is less than 15 m. The horizontal groundwater gradients are steep near mountain-front recharge areas and decrease towards the centers of the basins. A comparison of water levels from Akbari and others (2007) to water levels reported by Myslil and others (1982) indicates that water levels have declined more than 10 m in upslope areas and 5 to 6 m in the city of Kabul. Shallow lakes and marshes that were present in the city of Kabul in 1980 are now dry. Groundwater-level conditions in the Logar, Central Kabul, Deh Sabz, Paghman and Upper Kabul, and Shomali subbasins are discussed in Appendix 9. Monthly groundwater-level data have not been collected for the Panjsher River subbasin; however, conditions in this subbasin are likely to be similar to conditions in the northernmost parts of the Shomali subbasin, where the aquifer is influenced by Panjsher River losses.

Surficial and Neogene Aquifers

The groundwater resources of the Kabul Basin are generally considered to be the surficial (Quaternary) sediments (fig. 2) and consist primarily of loess, river channel sands and gravels, fan alluvium and colluvium, and unconsolidated sand

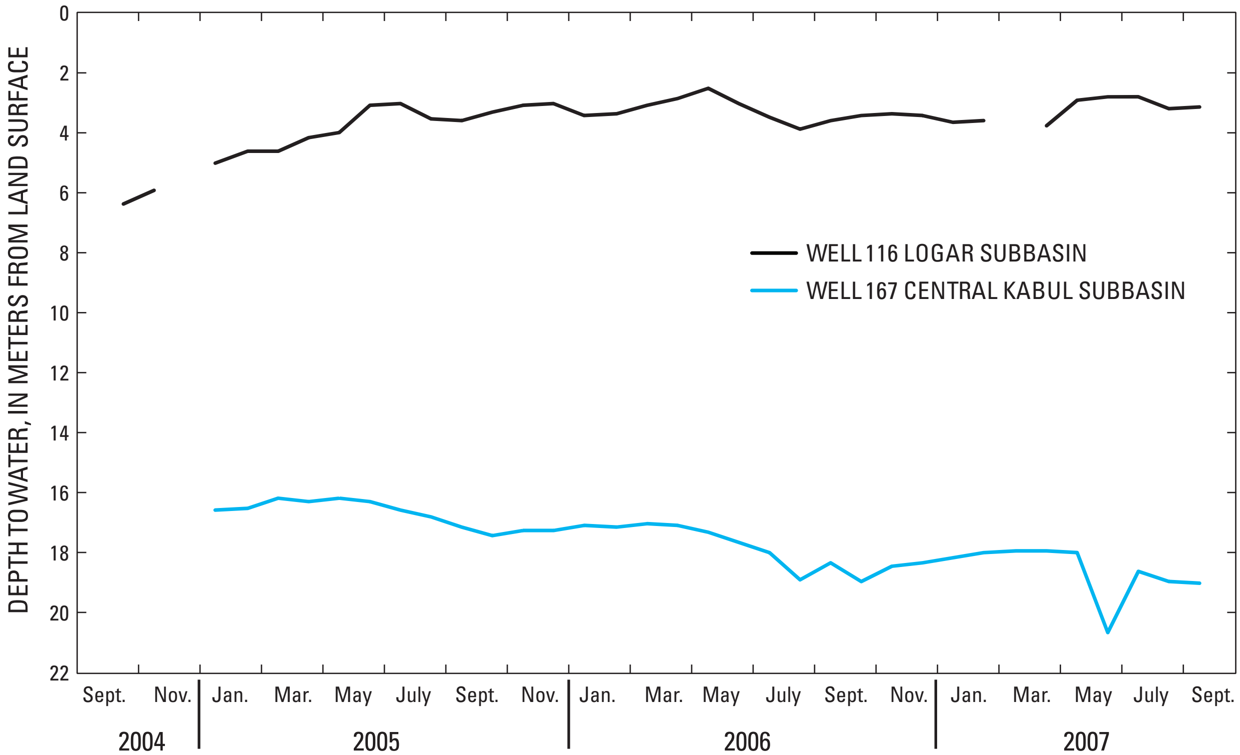


Figure 17. Monthly depth to water in wells 116, Logar subbasin, and 167, Central Kabul subbasin, between September 2004 and September 2007, in the Kabul Basin, Afghanistan.

and gravel. The thickness of these sediments is typically less than 80 m and increases to about 100 m toward the centers of the subbasins. The sediments generally have a high hydraulic conductivity of a few to about 100 m/d (horizontal). There is very little information on the underlying semiconsolidated fine-grained sediments and gravel which make up the Neogene aquifer. Geophysical investigations indicate that the depth to the base of these sediments may be as much as 600 to 1,000 m toward the center of some subbasins in the Kabul Basin (Japan International Cooperation Agency, 2007a, b; Homilius, 1969). Although the Neogene aquifer sediments predominantly consist of fine grained sand, silt, and clay, borehole geophysical logs of the former USSR PASSPORT wells (Amin Akbari, Afghanistan Geological Survey ,written commun., 2007) indicate that limited coarse-grained lenses are present in some areas of the Kabul Basin. Hydraulic properties of surficial and Neogene aquifer sediments are discussed in more detail in Appendix 6.

Water Quality

Water-quality samples were collected in the Kabul Basin in 2006 and 2007. Water collected from springs and karezes was considered to be more chemically similar to groundwater than surface-water samples collected in streams and rivers. For this reason, samples collected from springs and karezes were grouped with groundwater samples for statistical analyses. Seventy-seven surface-water samples were collected from 8 sites, and 92 groundwater samples were collected from 91 unique sites. Complete water-quality data are presented in Appendix 10.

Water-quality data were also grouped by subbasin or region (Western and East Front Source Areas). Minimum, maximum, mean, and median values were calculated for major ions, physical properties (table 4), and trace elements (table 5); however, not all water-quality parameters listed in tables 4 and 5 could be determined for each sample. For data that included censored values (results at or below detection limits), statistical measures were calculated by the Kaplan-Meier method (Helsel, 2005). The chemical compositions of the samples of surface water and groundwater collected from the different subbasins and regions were not significantly different from each other with the exception of samples collected from the Central Kabul subbasin (fig. 18). The temperature, specific conductance, and concentrations of total dissolved solids, *E. coli*, and NO_3 measured in groundwater collected in the Central Kabul subbasin were significantly greater than in samples of groundwater and surface water from all other subbasins with the exception of surface-water samples from the Paghman and Upper Kabul and Shomali subbasins. The Central Kabul subbasin may receive most of its recharge from leakage from the Paghman and Kabul Rivers. In the Central Kabul subbasin alone, there are no upland areas to supply recharge through lateral groundwater inflows.

Table 4. Summary statistics for physical properties and concentrations of major ions and bacteria by subbasin and region in the Kabul Basin, Afghanistan between- May 2006 and July 2007.

[m, meters; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; Alk, titration alkalinity; <, less than; > greater than or equal to; –, not applicable]

Region	Statistic	Well depth (m)	Sample water level (m)	Water temperature (° C)	Specific conduc - tance (µS/cm)	pH field	O^2 mgL	Total coli counts/ 100 mL	*E. coli* counts/ 100 mL	NO_3 N mg/L	Ca mg/L
Groundwater - Subbasin											
Central Kabul	Number of samples	26	25	28	28	28	6	25	24	13	13
	min	6.6	3.1	14.5	410	5.9	0.1	1	1	0.6	35.6
	max	160.0	57.5	22.5	7,350	8.3	0.2	>2,420	461	27.1	221.4
	mean	56.6	14.3	18.1	1,678	–	0.1	692	21	9.9	76.6
	median	40.0	10.6	18.0	1,177	7.7	0.1	84	1	6.7	57.3
Deh Sabz	Number of samples	5	4	5	3	5	1	4	5	6	3
	min	30.0	14.4	15.8	507	7.1	1.9	2	1	3	49.8
	max	60.0	32.1	20.1	2,374	7.7	1.9	>2,420	461	6	70.3
	mean	46.9	19.6	18.1	1,303	–	–	1,043	157	4.3	59.4
	med	52.0	15.1	18.2	1,204	7.4	–	18	12	3.8	58.2
Eastern Front Source Area	Number of samples	3	4	7	6	8	1	1	2	6	6
	min	7	5	13	303	7.3	1.4	4	4	1	41.4
	max	185	41	21	754	8.3	1.4	4	219	3	76.3
	mean	114.1	27.3	17.2	520	–	–	–	112	1.8	56.2
	med	150.0	26.4	17.7	507	8.0	–	–	–	1.2	51.4
Logar	Number of samples	11	10	12	4	12	2	10	10	4	4
	min	25.0	2.5	13.0	693	7.4	0.1	1	1	1	39.1
	max	79.1	10.7	16.2	1,595	8.2	0.3	>2,420	248	9	70.8
	mean	50.0	6.3	14.9	1,159	–	0.2	657	28	3.5	58.8
	median	54.3	6.4	15.1	1,155	7.8	0.3	35	1	1.6	56.2
Paghman and Upper Kabul	Number of samples	14	13	15	15	15	2	11	11	6	6
	min	25.0	3.2	12.7	317	7.4	0.1	1	1	1	35.1
	max	99.7	36.1	19.5	2,241	8.1	0.1	>2,420	13	13	103.3
	mean	52.2	12.0	15.8	829	–	0.1	283	2	5.2	73.1
	median	47.8	8.8	15.6	755	7.7	0.1	11	1	3.2	73.2
Shomali	Number of samples	8	8	11	11	11	2	8	8	7	7
	min	9.0	6.4	13.7	411	5.8	0.1	1	0	2	56.3
	max	102.0	27.0	18.6	2,199	8.0	0.3	2,419	18	4	108.0
	mean	56.1	16.3	15.6	836	–	0.3	894	5	2.8	75.7
	median	40.0	13.9	15.5	589	7.3	0.3	276	3	2.4	67.8
Western Front Source Area	Number of samples	11	11	13	13	13	3	8	8	4	4
	min	4.9	3.4	11.0	248	7.1	0.1	1	0	2	45.0
	max	97.0	32.0	18.2	1,000	8.4	0.2	>2,420	125	40	116.6
	mean	36.6	12.3	14.6	530	–	0.2	1,167	19	12.1	78.4
	median	39.0	10.3	14.4	518	7.3	0.2	1,046	1	2.2	60.1
Kabul Basin - all groundwater	Number of samples	78	75	91	92	92	17	67	68	43	43
	min	4.9	2.5	11.0	248	8.4	0.1	1	0	0.6	35.1
	max	185.0	57.5	22.5	7,350	5.8	1.9	>2,420	461	40.2	221.4
	mean	53.6	13.7	16.4	1,088	–	0.3	725	29	6.2	70.4
	median	60.0	10.3	16.1	1,204	7.6	0.1	73	1	3.3	65.1