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Conceptual Model of Water Resources in the Kabul Basin, Afghanistan

Scientific Investigations Report 2009–5262

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photograph showing water sample being collected by the Afghan Geological Survey at a refugee camp in the Kabul Basin. (Photograph by Ingrid M. Verstraeten, U.S. Geological Survey)

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Conversion Factors, Datums, Acronyms and Abbreviations, and Place Names

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.

Conceptual Model of Water Resources in the Kabul Basin, Afghanistan

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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

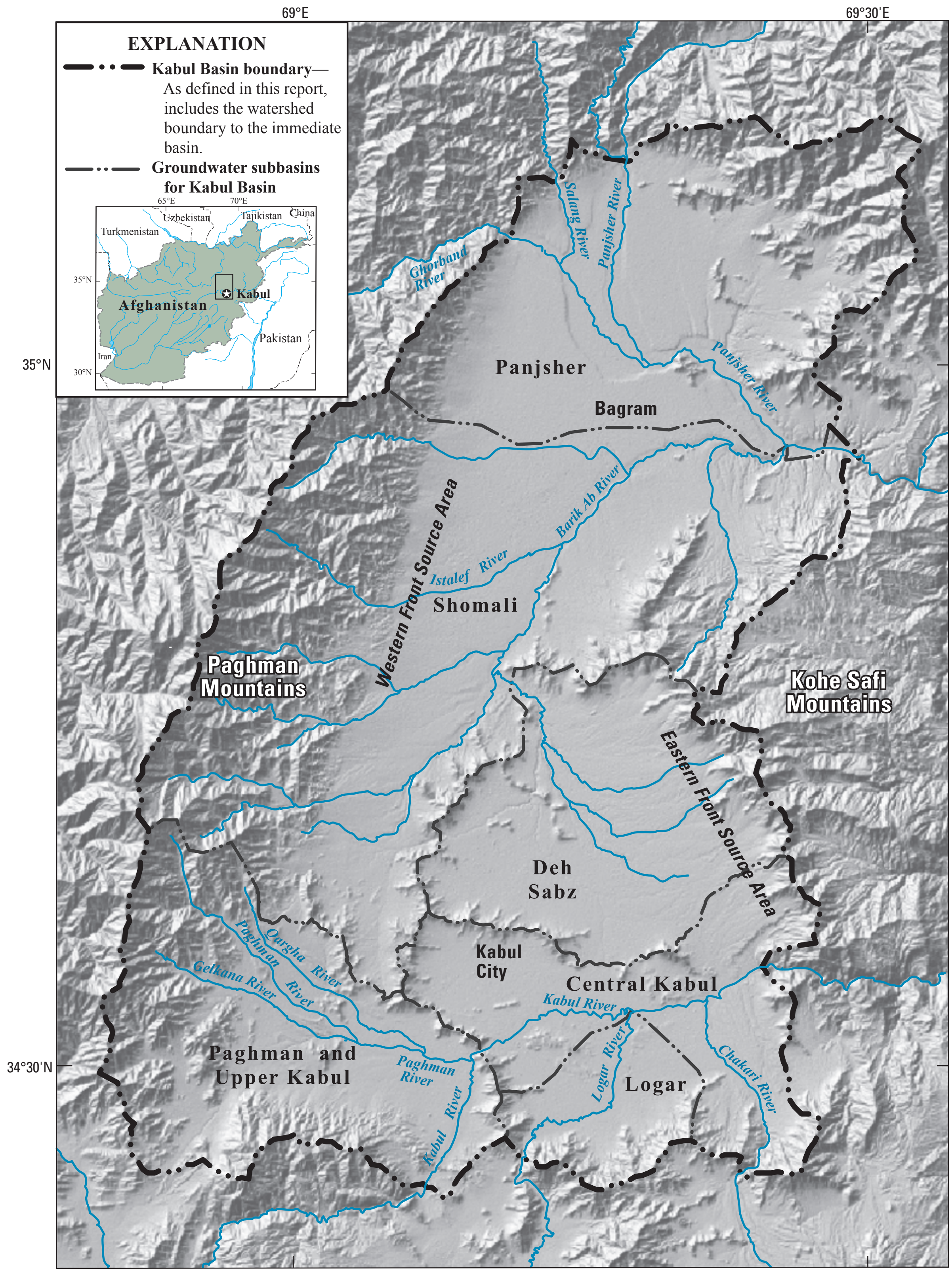
The availability of water resources is vital to the social and economic well-being and rebuilding of Afghanistan. With refugees returning during periods of relative security, the city of Kabul in 2006 had a population of about 4 million. Rapid population growth and changing climate conditions have placed 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.



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 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

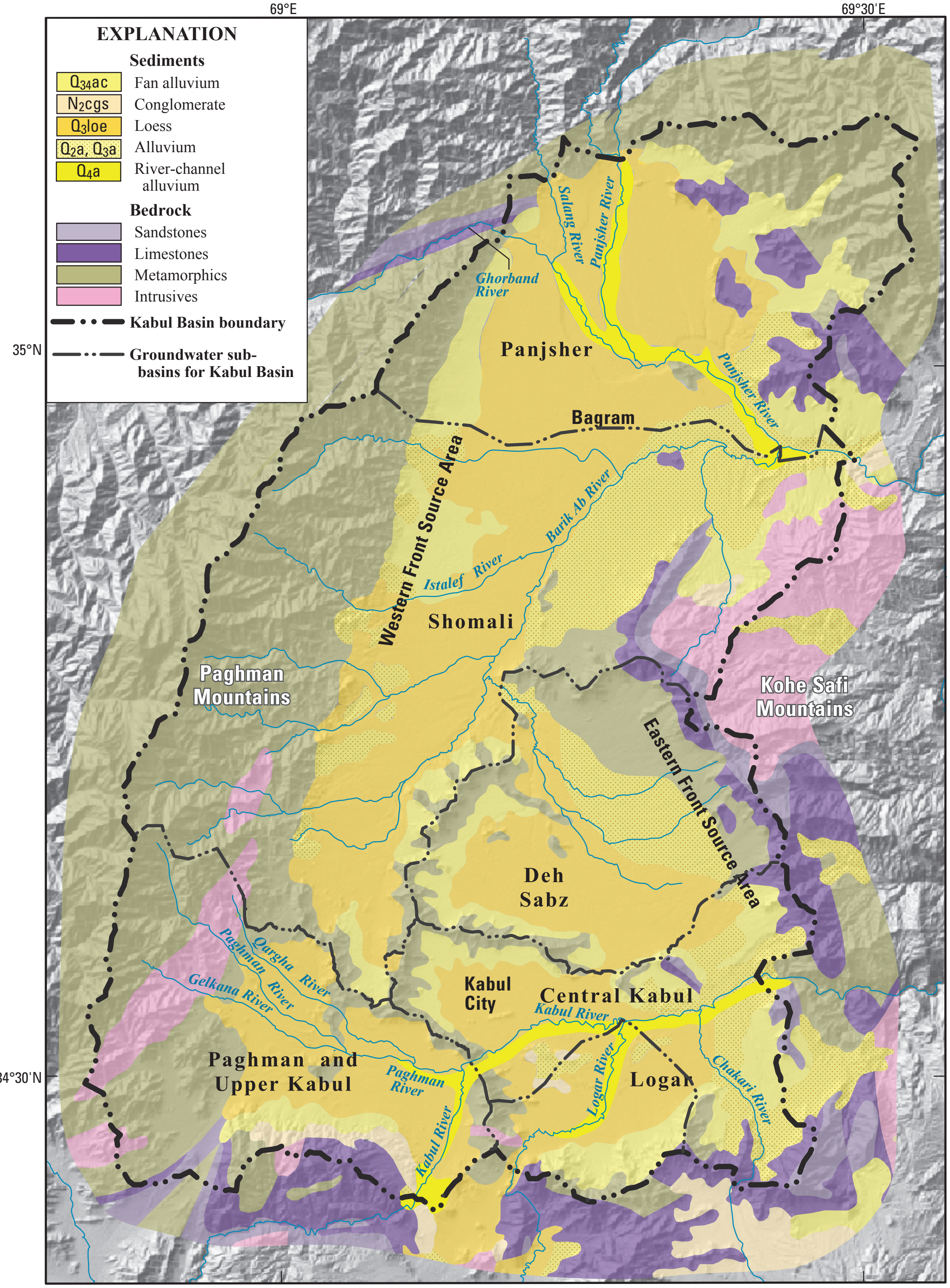
The topography of the Kabul Basin is strongly influenced by regional and local tectonic activity and by fluvial processes. The basin is bounded by mountain ranges; the highest range, reaching 4,400 m in altitude, is the Paghman Mountains to the west of the study area. The Kohe Safi range to the east 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.



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

Geology codes from Bohannon and Turner, 2007; and Lindsay and others, 2005

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

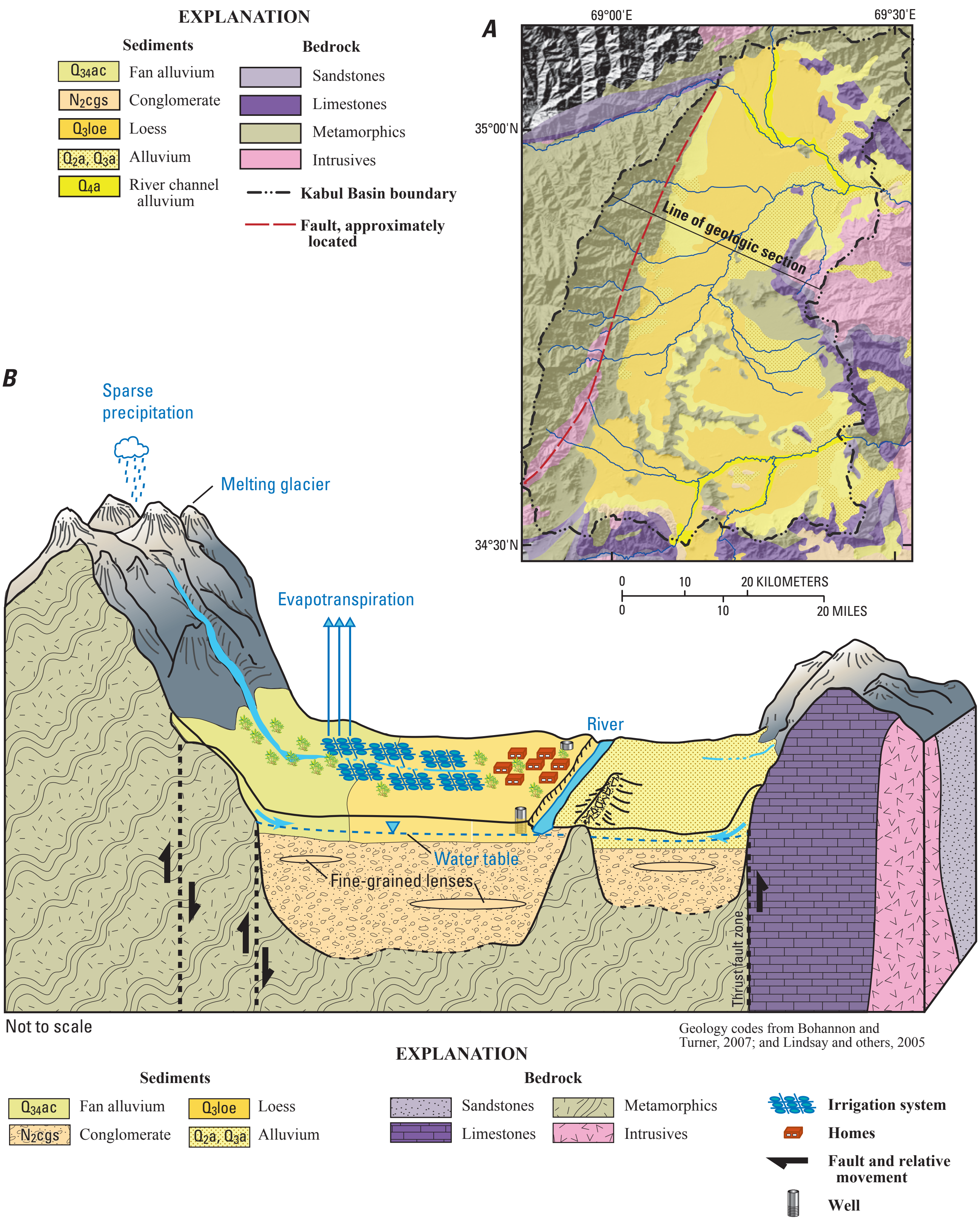


Figure 3. Planar view (A) and generalized hydrogeologic cross section (B) of the Kabul Basin, Afghanistan.

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.

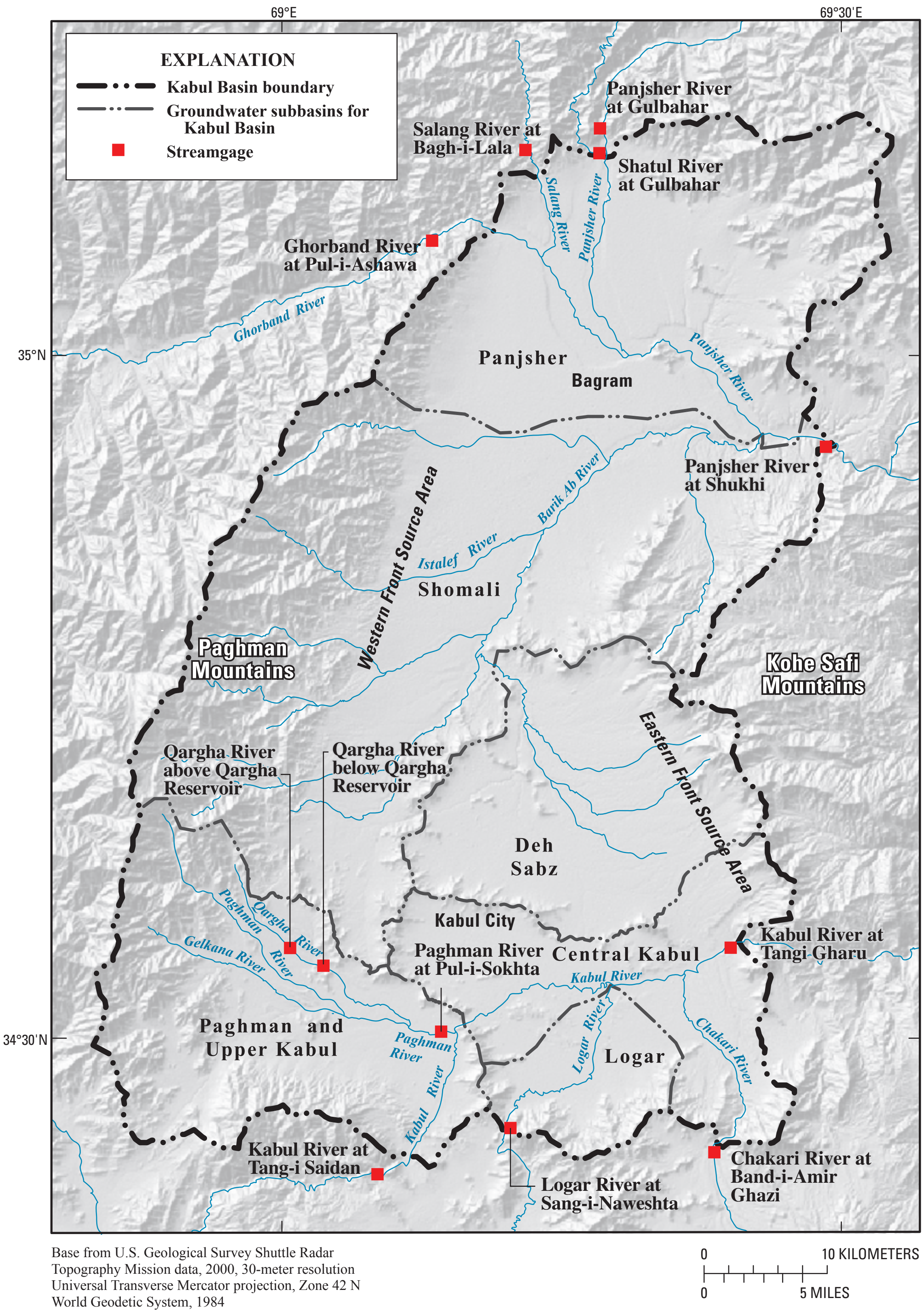


Figure 4. Locations of historical streamgages in the Kabul Basin, Afghanistan.

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.

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.

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

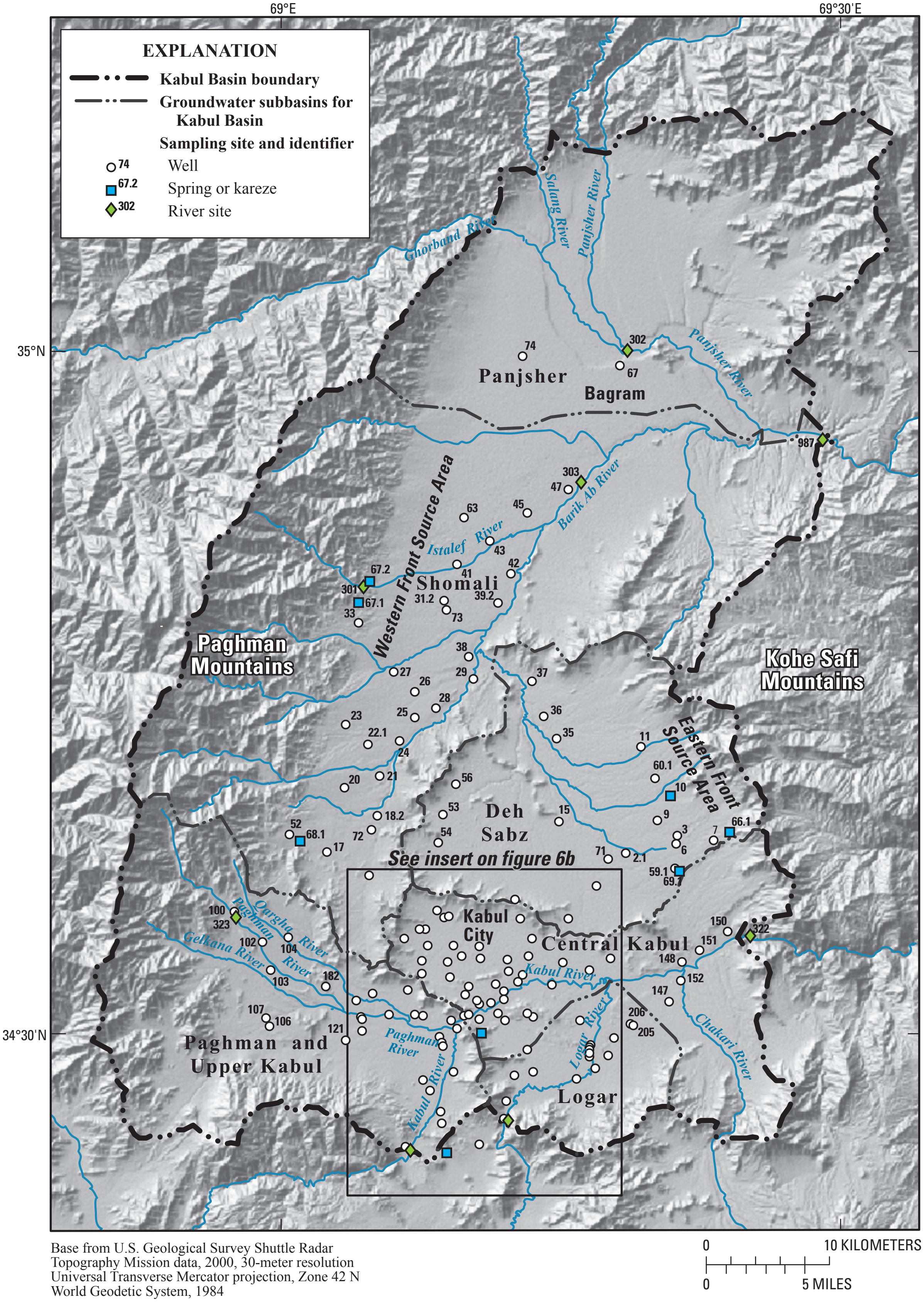


Figure 6. Locations of wells in the groundwater-level-monitoring network in the Kabul Basin, Afghanistan.

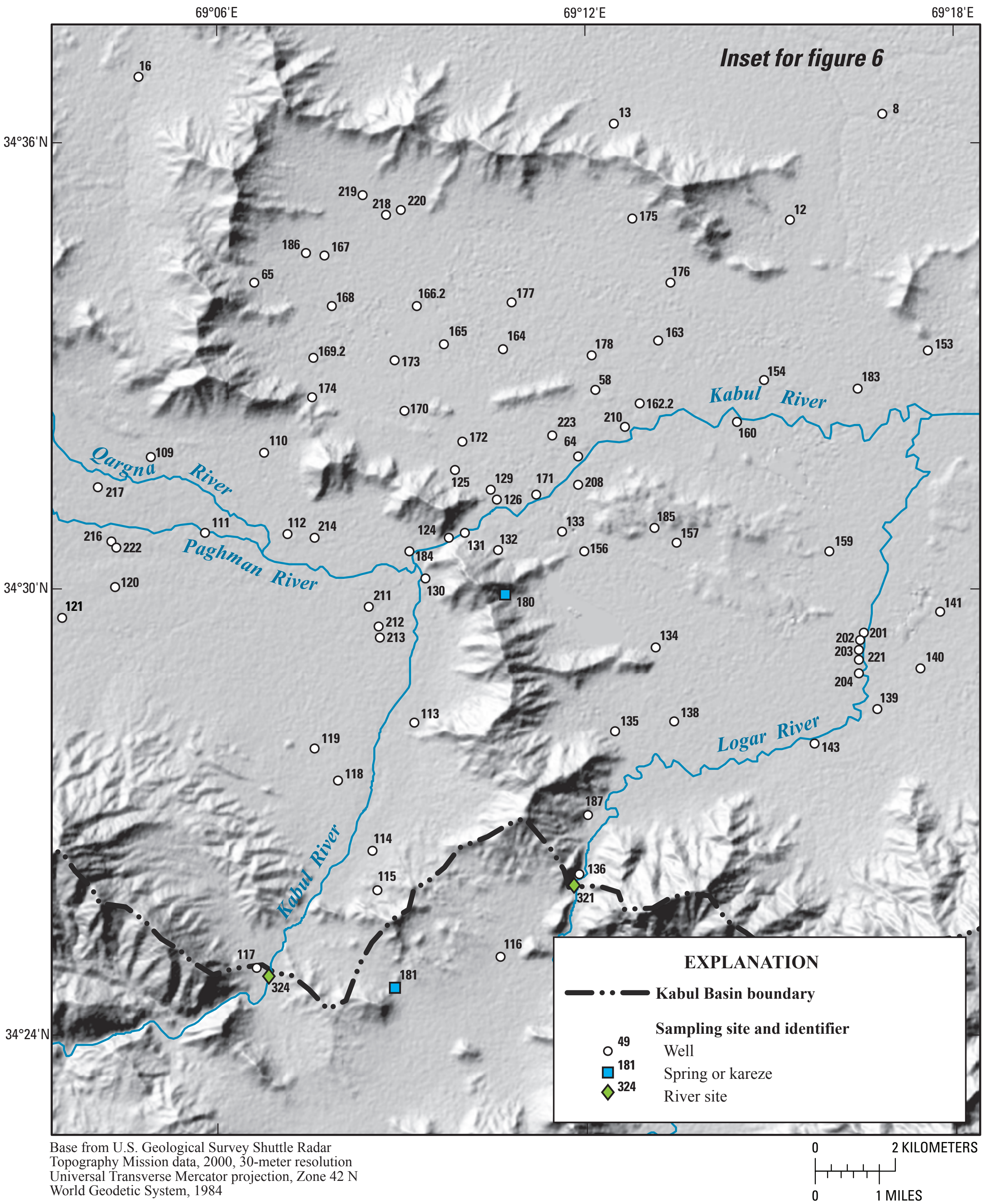


Figure 6. Continued.

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.

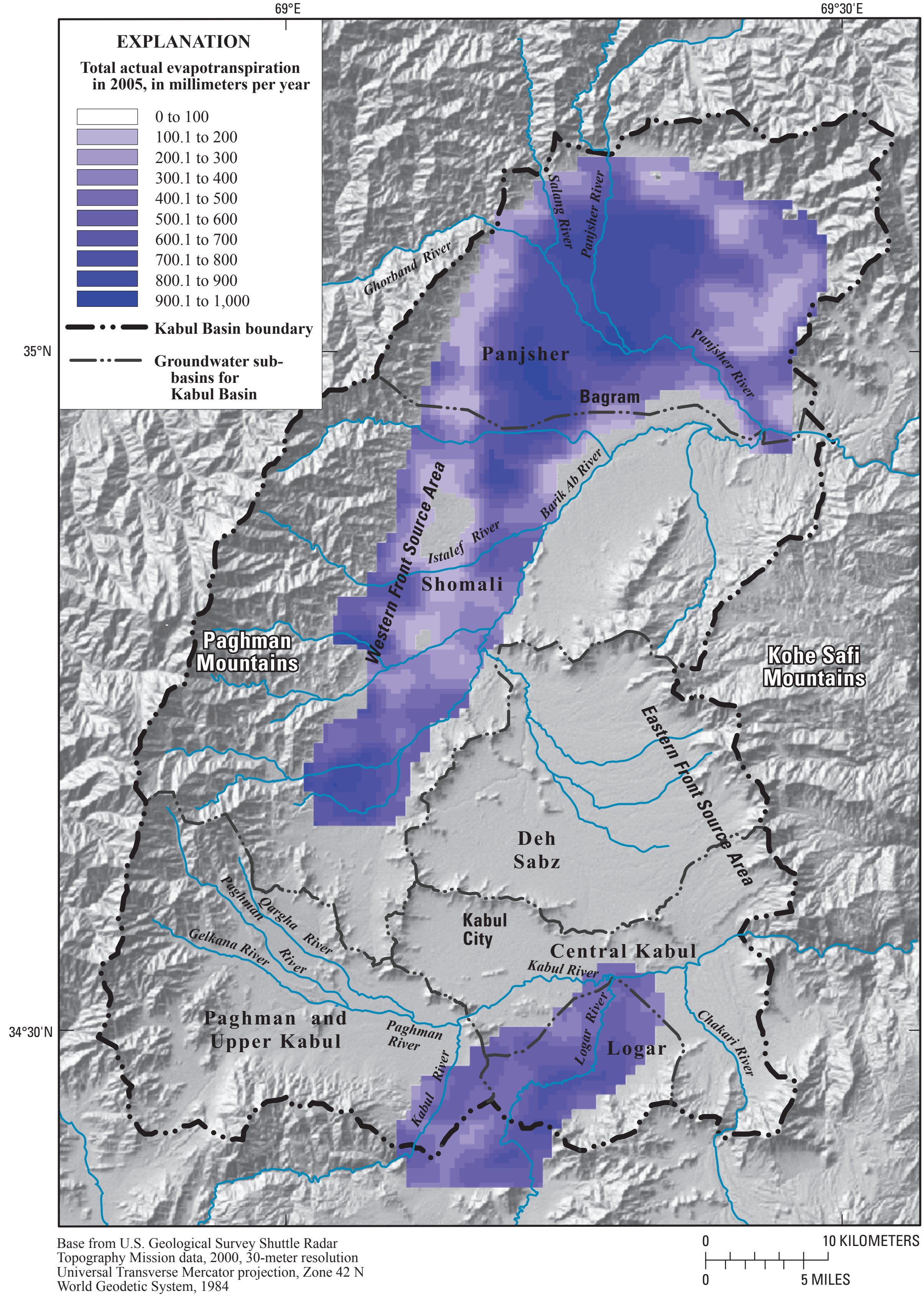


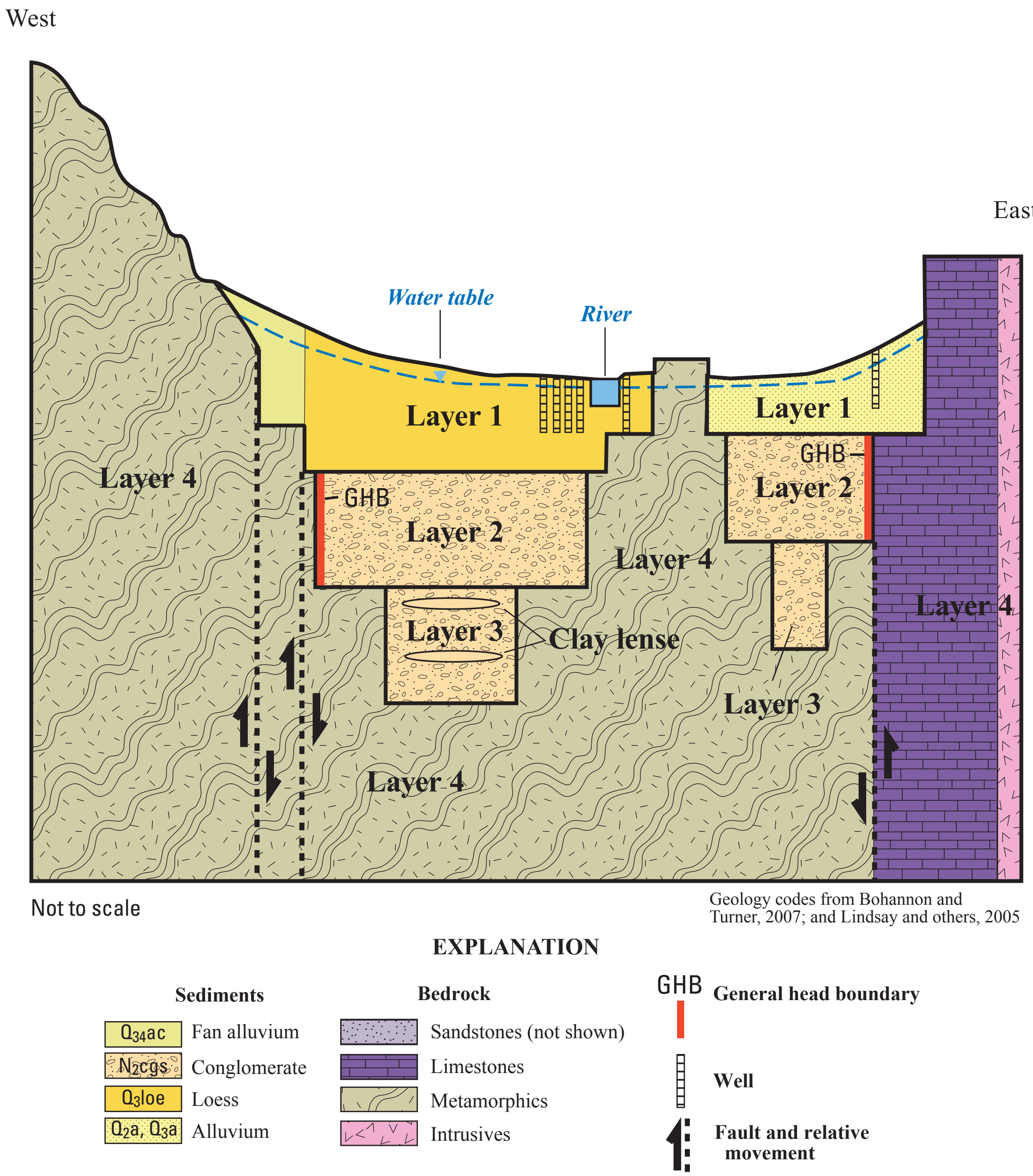
Figure 7. Areas of estimated actual evapotranspiration (AET) in the Kabul Basin, Afghanistan.

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).

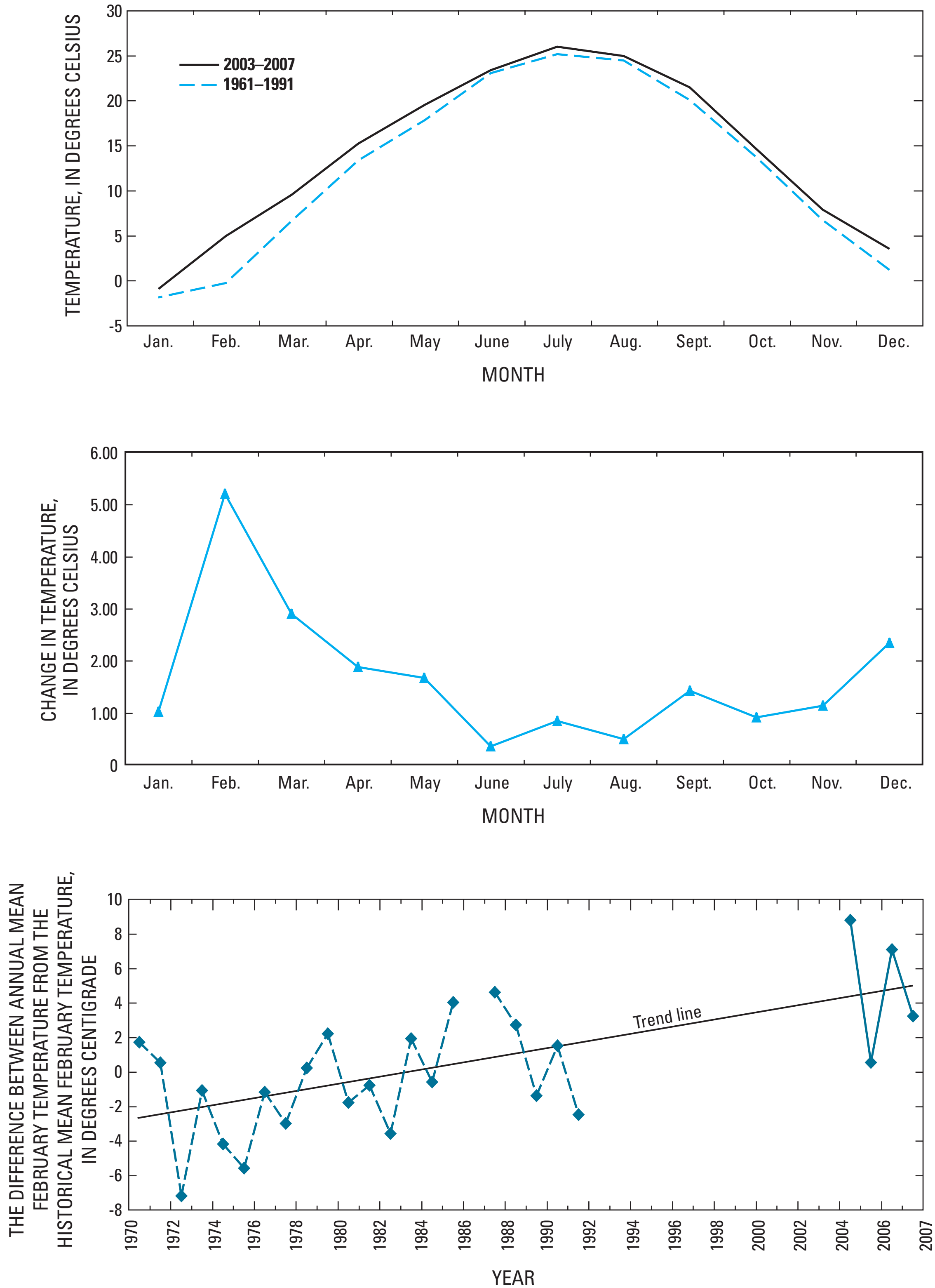


Figure 9. (A) Annual graphs of mean monthly temperatures for the 1961–1991 and 2003–2007 periods; (B) increases in mean monthly temperatures from 1961–1991 to 2003–2007; and (C) warming trend in the mean February temperature for 1970–2006 at Kabul, Afghanistan.

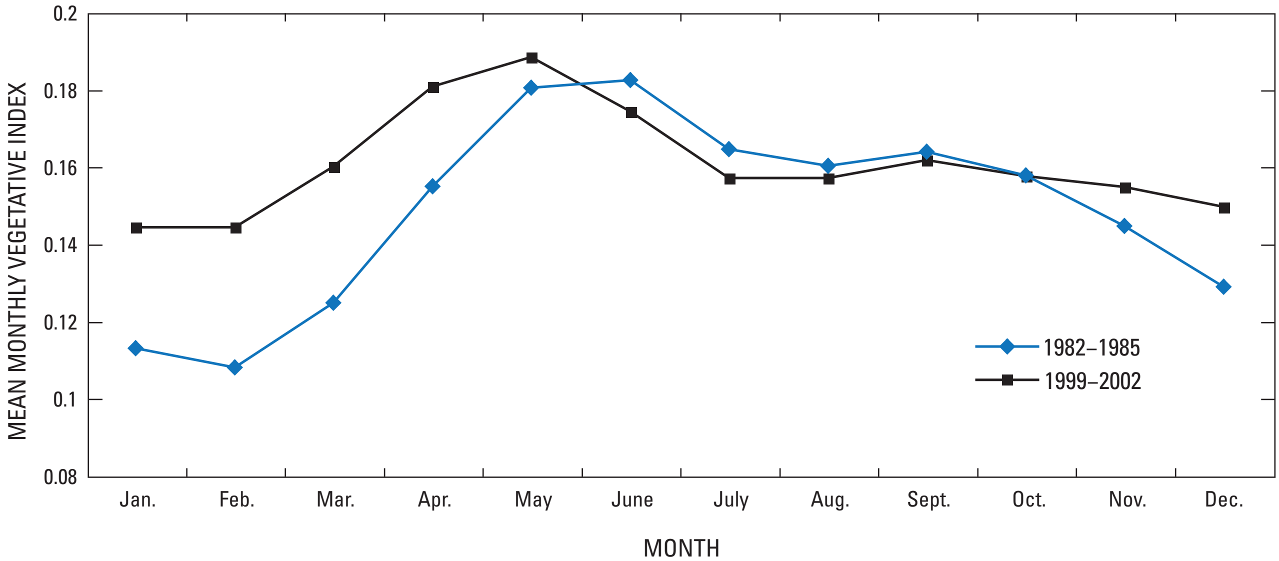


Figure 10. The mean monthly vegetative index (NDVI), or greenness, for 1982–1985 and 1999–2002, for the Kabul Basin, Afghanistan.

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-SO_4-Cl and Na-CO_3-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.

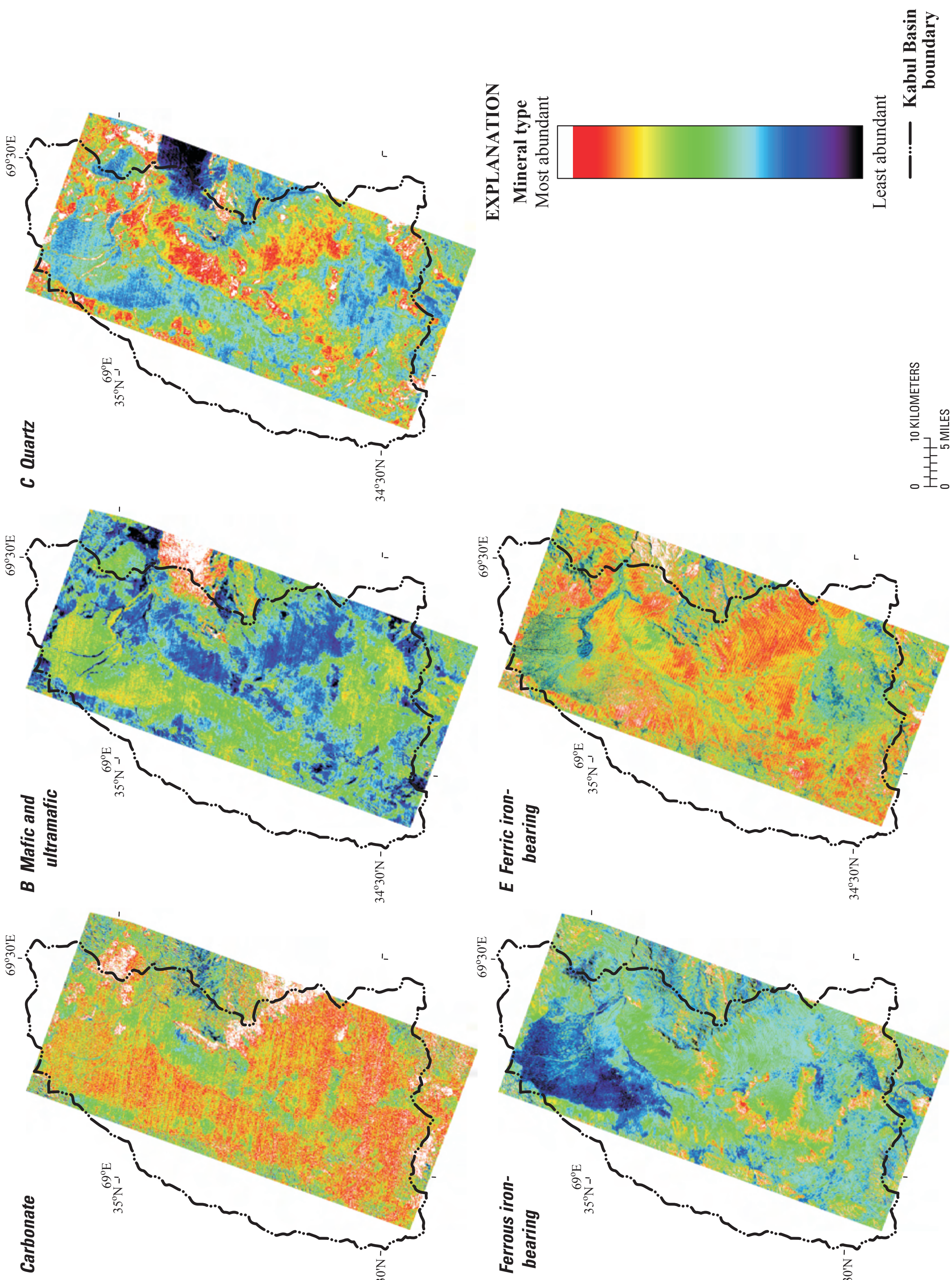


Figure 11. ASTER analysis of relative abundance of mineral groups containing (A) carbonate, (B) mafic and ultramafic minerals, (C) quartz, (D) ferrous iron, and (E) ferric iron in the Kabul Basin, Afghanistan.

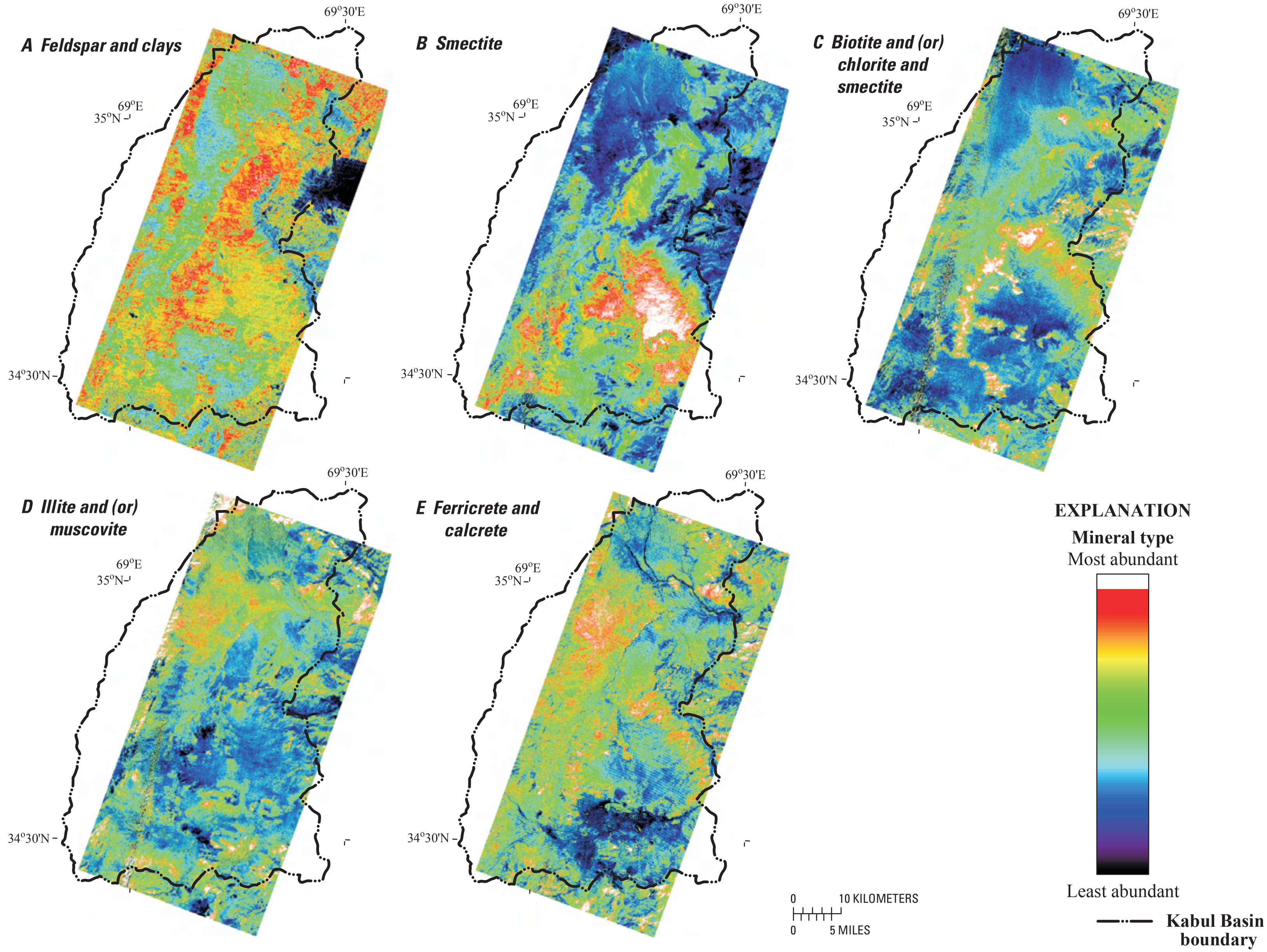


Figure 12. ASTER analysis of relative abundance of mineral groups containing (A) feldspar and clays, (B) smectite clays, (C) biotite and (or) chlorite and smectite, (D) illite and (or) muscovite, and (E) ferricrete and calcrete minerals in the Kabul Basin, Afghanistan.

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.

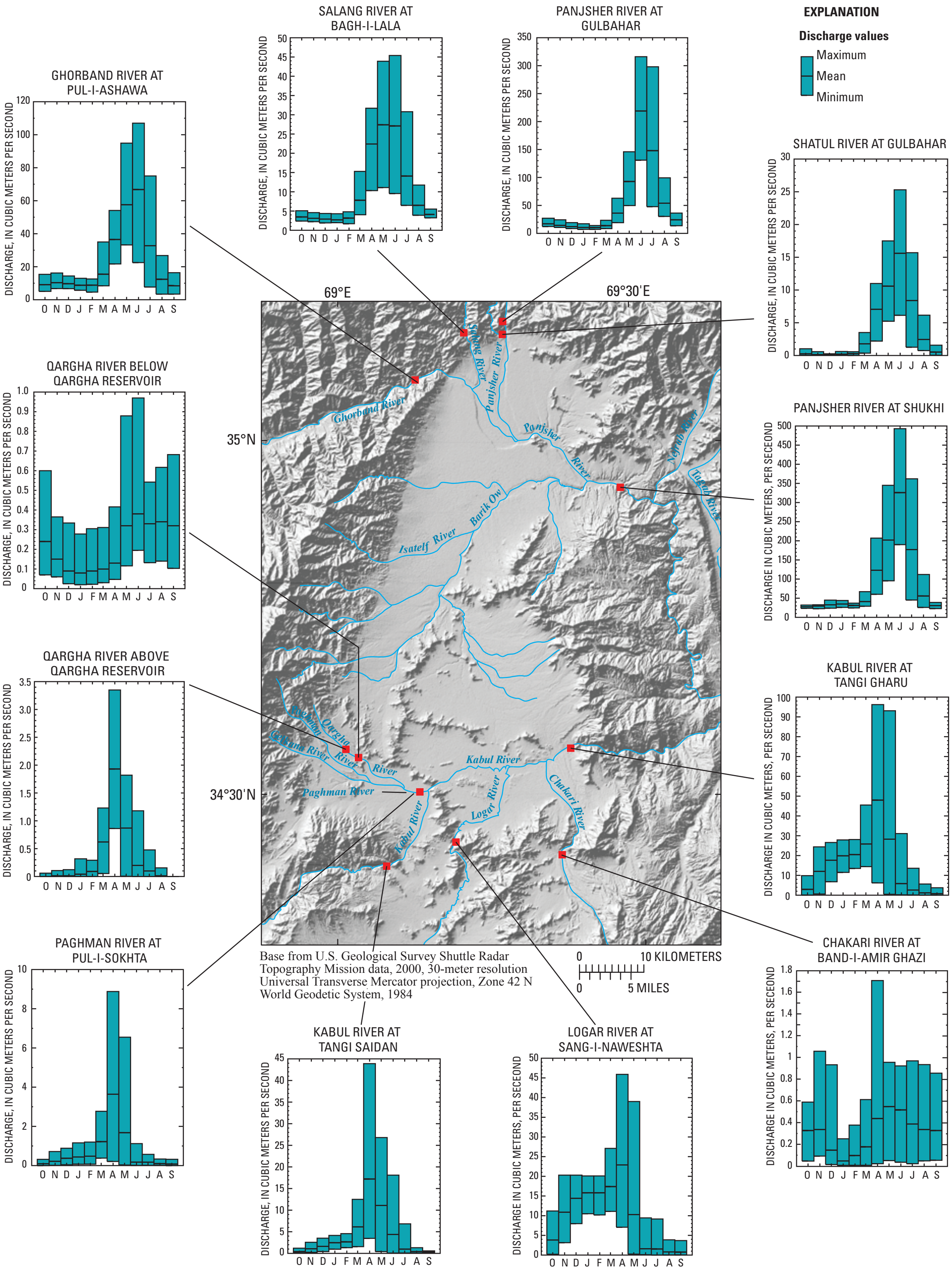


Figure 13. Maximum, minimum, and mean monthly discharges for the periods of record at 12 streamgages in the Kabul study area.

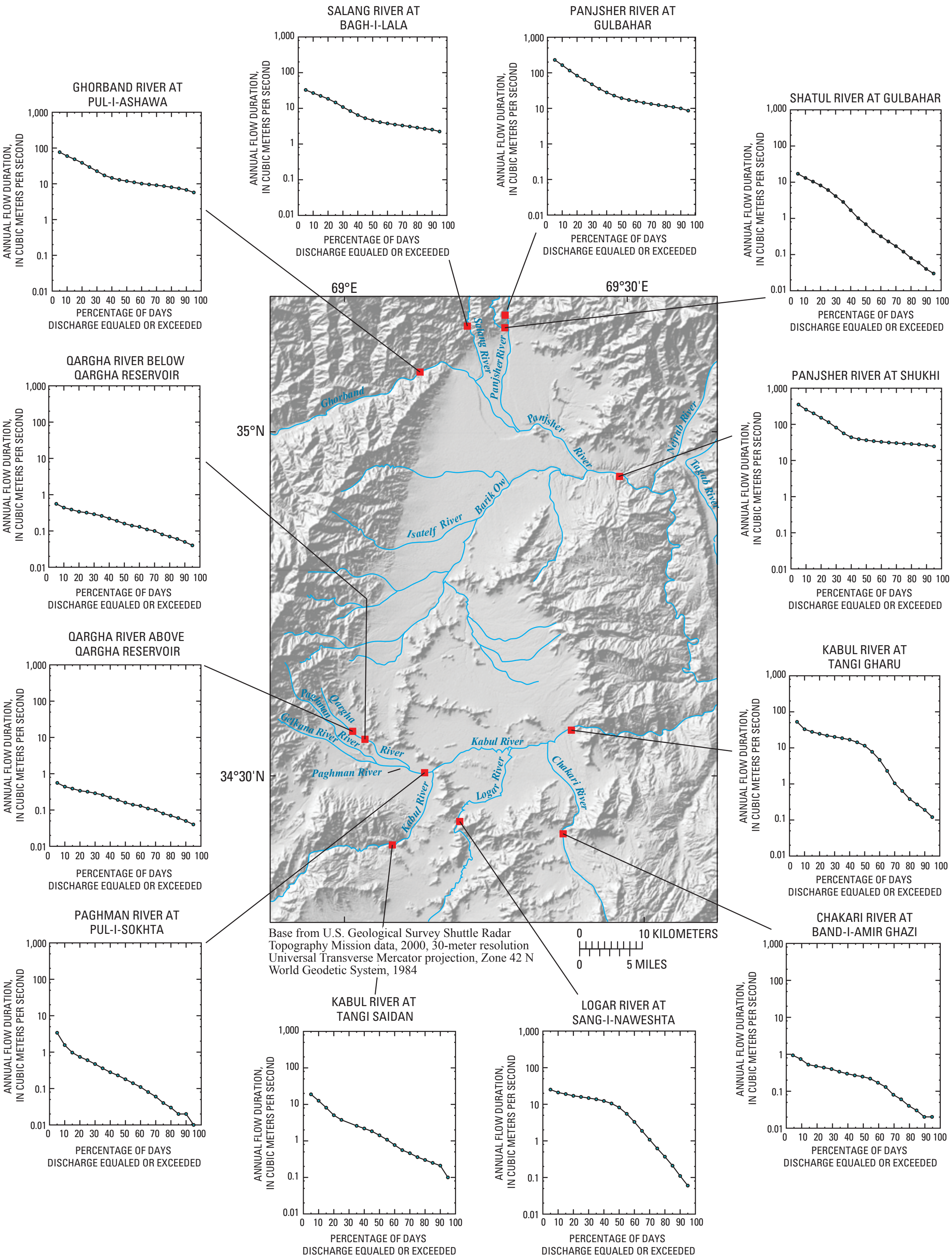


Figure 14. Annual streamflow durations for the periods of record at streamgages in the Kabul study area.

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.

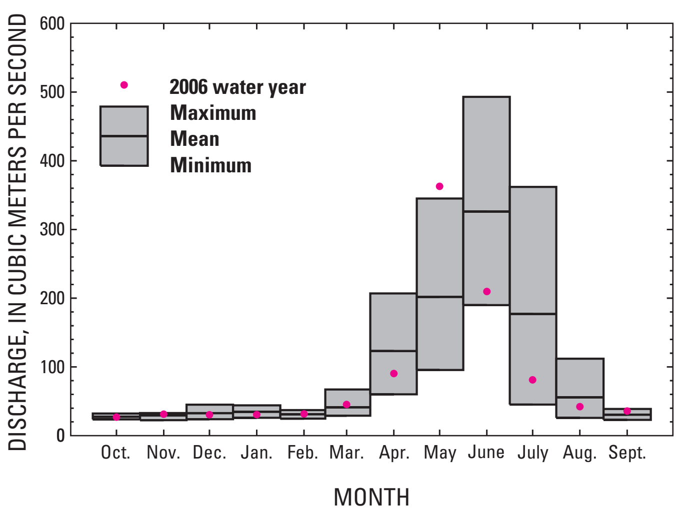


Figure 16. Comparison of the 2006 water-year monthly mean discharges with historical mean monthly discharges for the streamgage Panjsher River at Shukhi.

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

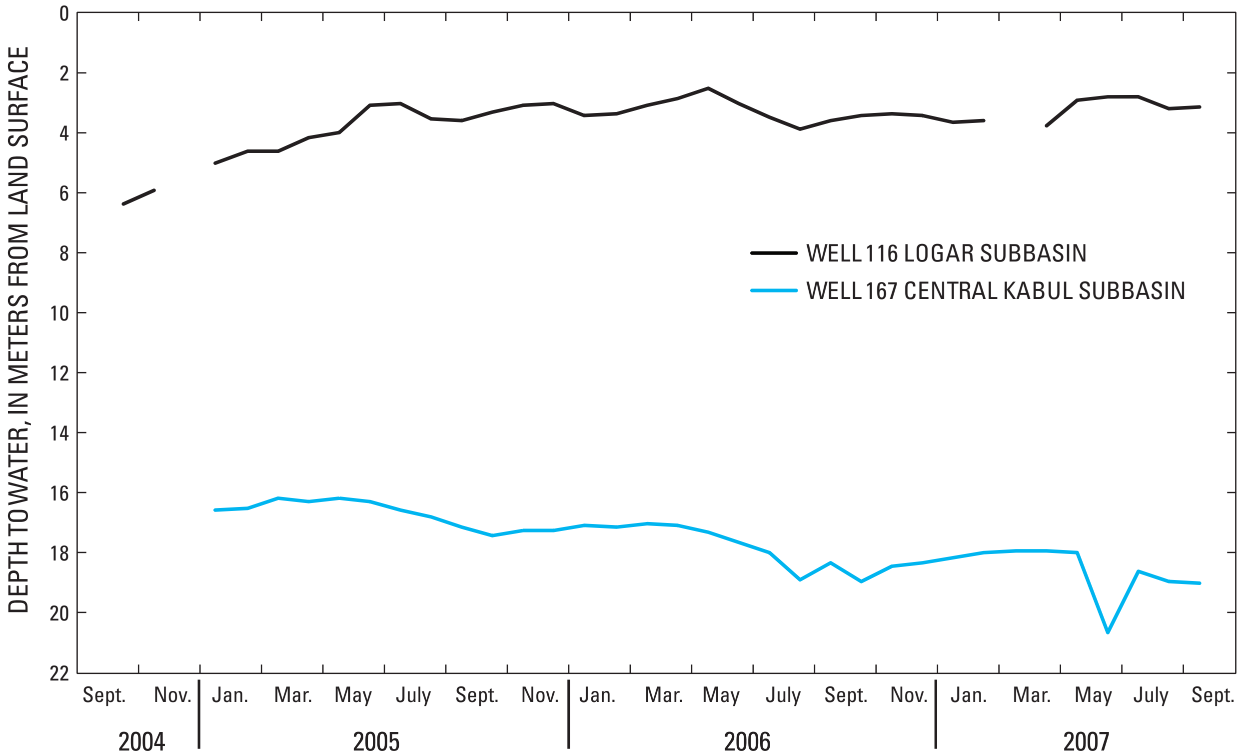


Figure 17. Monthly depth to water in wells 116, Logar subbasin, and 167, Central Kabul subbasin, between September 2004 and September 2007, in the Kabul Basin, Afghanistan.

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

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.—Continued

[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	Mg mg/L	Na mg/L	K mg/L	Alk mg/L as $CaCO_3$	Cl mg/L	SO_4 mg/L	F mg/L	Br mg/L	SiO_2 mg/L
Groundwater - Subbasin										
Central Kabul	Number of samples	13	13	13	13	13	13	12	13	13
	min	8.1	14.6	2.8	126.0	7.3	25.2	<0.05	<0.05	10.8
	max	269.0	1,230.0	17.4	532.0	1,650.0	1,323.0	1.61	2.43	41.1
	mean	84.8	190.5	9.6	307.4	261.4	270.8	0.40	0.49	26.3
	median	62.3	72.6	8.5	307.4	98.7	90.3	0.29	0.16	25.7
Deh Sabz	Number of samples	3	3	3	3	3	3	3	3	3
	min	14.7	35.1	4.4	137.9	29.2	86.3	0.38	0.08	30.4
	max	42.6	139.0	5.0	220.0	67.9	292.0	0.62	0.29	41.1
	mean	26.8	75.9	4.6	175.4	46.1	174.1	0.51	0.18	34.0
	med	23.0	53.6	4.5	168.0	41.2	144.0	0.54	0.17	30.6
Eastern Front Source Area	Number of samples	6	6	6	6	6	6	6	6	6
	min	12.6	1.4	0.7	144.0	1.7	14.5	0.16	<.05	6.3
	max	37.2	65.1	2.9	311.0	29.0	140.0	0.36	0.16	19.0
	mean	28.6	27.2	1.6	231.4	13.7	62.5	0.25	0.06	15.9
	med	28.8	18.1	1.3	208.6	8.3	50.5	0.20	<.05	17.3
Logar	Number of samples	4	4	4	5	4	4	4	4	4
	min	30.4	61.3	4.5	319.0	58.6	40.6	0.25	0.08	19.0
	max	87.9	96.5	6.9	467.0	92.0	138.0	0.49	0.23	26.3
	mean	64.9	74.6	5.3	386.4	74.3	91.2	0.36	0.15	22.7
	median	61.8	70.4	4.7	385.0	63.2	80.2	0.27	0.13	22.7
Paghman and Upper Kabul	Number of samples	6	6	6	7	6	6	6	6	6
	min	12.5	10.2	1.6	148.0	3.6	10.8	0.20	<.05	18.5
	max	74.7	87.9	6.7	398.0	103.0	122.0	0.57	0.19	31.2
	mean	37.1	39.5	4.4	286.2	39.4	62.3	0.31	0.08	24.2
	median	23.0	29.9	3.7	259.0	23.4	28.4	0.24	0.06	21.1
Shomali	Number of samples	7	7	7	7	7	7	7	7	7
	min	14.2	9.4	2.7	201.0	3.6	7	0.11	<.05	15.9
	max	70.5	108.0	13.0	401.0	139.0	174	0.28	0.22	28.0
	mean	31.8	38.4	5.7	287.5	43.4	47.8	0.22	0.06	23.9
	median	28.1	18.6	4.0	270.6	11.2	19.9	0.24	<0.5	24.7
Western Front Source Area	Number of samples	4	4	4	6	4	4	4	4	4
	min	7.4	6.6	1.2	148.0	2.7	4.3	0.11	<.05	17.6
	max	32.1	23.4	4.2	303.0	64.8	23.8	0.59	0.07	27.3
	mean	16.7	12.7	2.8	211.7	19.4	11.2	0.28	0.02	22.0
	median	8.2	9.0	2.5	210.0	4.5	7.8	0.19	<0.05	19.2
Kabul Basin - all groundwater	Number of samples	43	43	43	47	43	43	42	47	43
	min	7.4	1.4	0.7	126.9	1.7	4.3	<.05	<.05	6.3
	max	269.0	1,230.0	17.4	532.0	1,650.0	1,323.0	1.61	2.43	41.1
	mean	49.4	86.6	5.7	279.3	105.4	128.7	0.33	0.19	24.0
	median	31.4	47.8	4.5	262.4	29.2	80.2	0.25	0.11	28.0

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.—Continued

[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
Surface water - Subbasin and River(s)											
Central Kabul	Number of samples	–	–	11	11	11	–	1	1	8	8
	min	–	–	0.8	366	8.6	–	>2,420	>2,420	2.3	39.1
Kabul River at Tangi-Gharu	max	–	–	22.9	929	9.0	–	>2,420	>2,420	3.9	60.6
	mean	–	–	11.2	662	–	–	–	–	3.0	52.0
	median	–	–	10.0	742	8.8	–	–	–	2.9	55.8
Logar	Number of samples	–	–	11	11	11	–	1	1	7	7
	min	–	–	0.5	412	8.6	–	1,120	162	1.4	48.3
Logar River	max	–	–	22.2	1,215	8.8	–	1,120	162	3.4	55.6
	mean	–	–	8.4	661	–	–	–	–	2.1	51.7
	median	–	–	7.8	623	8.8	–	–	–	1.9	50.2
Paghman and Upper Kabul	Number of samples	–	–	12	12	12	–	1	1	8	8
	min	–	–	3.7	67	8.4	–	116	42	0.4	8.1
Paghman River	max	–	–	18.0	143	9.0	–	116	42	1.3	16.3
	mean	–	–	10.0	110	–	–	–	–	0.9	12.6
	median	–	–	8.5	111	8.9	–	–	–	1.0	13.8
	Number of samples	–	–	10	10	10	–	1	1	6	6
	min	–	–	2.7	277	8.3	–	1,414	387	2.1	35.5
Kabul River at Tangi Saidan	max	–	–	14.7	786	8.6	–	1,414	387	3.3	72.4
	mean	–	–	8.0	515	–	–	–	–	2.6	51.5
	median	–	–	6.4	508	8.5	–	–	–	2.5	41.9
Shomali	Number of samples	–	–	13	13	13	–	–	1	7	7
	min	–	–	4.2	78	8.4	–	–	>2,420	0.5	10.6
Istalef River	max	–	–	17.8	196	8.8	–	–	>2,420	1.9	21.3
	mean	–	–	8.6	140	–	–	–	–	1.3	16.7
	median	–	–	11.0	140	8.5	–	–	–	1.3	16.9
	Number of samples	–	–	8	8	8	–	1	1	5	5
	min	–	–	0.6	114	8.3	–	>2,420	>2,420	1.4	20.5
Barik Ab River	max	–	–	14.8	1,497	8.6	–	>2,420	>2,420	5.9	88.6
	mean	–	–	7.0	568	–	–	–	–	2.7	46.7
	median	–	–	7.5	496	8.5	–	–	–	2.0	43.4
Panjsher	Number of samples	–	–	11	11	11	–	2	2	7	7
	min	–	–	9	232	8	–	435	70	0.7	29.3
Panjsher River at Sayad	max	–	–	15	474	9	–	649	99	1.4	53.2
	mean	–	–	11.1	363	–	–	–	–	1.1	39.9
	median	–	–	11.2	401	8.4	–	–	–	1.1	33.0
	Number of samples	–	–	–	–	–	–	–	–	1	1
	min	–	–	–	–	–	–	–	–	0.8	26.7
Panjsher River at Shukhi[1]	max	–	–	–	–	–	–	–	–	0.8	26.7
	mean	–	–	–	–	–	–	–	–	–	–
	median	–	–	–	–	–	–	–	–	–	–

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.—Continued

[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	Mg mg/L	Na mg/L	K mg/L	Alk mg/L as $CaCO_3$	Cl mg/L	SO_4 mg/L	F mg/L	Br mg/L	SiO_2 mg/L
Surface water - Subbasin and River(s)										
Central Kabul	Number of samples	8	8	8	8	8	8	8	8	8
	min	12.6	11.8	2.3	140.0	10.5	19.2	0.13	<.05	9.1
Kabul River at Tangi-Gharu	max	43.5	59.7	6.7	294.0	70.0	89.9	0.31	0.15	19.2
	mean	29.1	34.5	4.2	228.5	35.0	49.4	0.22	0.06	14.3
	median	32.2	37.8	4.0	229.3	36.8	51.0	0.20	0.06	14.4
Logar	Number of samples	7	7	7	7	7	7	7	7	7
	min	21.7	22.6	2.8	199.2	18.5	31.8	0.2	0.05	12.6
Logar River	max	71.8	97.2	6.5	386.0	108.0	113.0	0.4	0.19	21.6
	mean	37.5	42.3	3.9	266.1	40.5	53.9	0.28	0.07	15.4
	median	38.8	42.1	3.8	268.8	37.8	51.0	0.29	0.07	15.7
Paghman and Upper Kabul	Number of samples	8	8	8	8	8	8	8	8	8
	min	1.4	2.1	0.8	22.8	0.9	4.3	<.05	<.05	6.7
Paghman River	max	2.1	3.3	1.4	48.6	2.3	6.8	0.06	<.05	9.5
	mean	1.8	2.8	1.0	36.1	1.6	5.5	0.01	–	7.6
	median	1.9	3.0	0.9	39.6	1.4	5.4	<.05	<.05	7.0
	Number of samples	6	6	6	6	6	6	6	6	6
	min	6.9	5.2	1.5	110.9	4.2	9.2	0.08	<.05	9.4
Kabul River at Tangi Saidan	max	22.2	19.9	3.4	259.8	21.9	17.3	0.12	<.05	14.8
	mean	12.8	10.5	2.1	173.2	10.6	13.1	0.11	–	11.8
	median	8.8	6.6	1.7	130.2	5.8	11.4	0.12	–	11.0
Shomali	Number of samples	7	7	7	7	7	7	7	7	7
	min	1.4	2.0	1.6	32.0	0.8	2.7	<.05	<.05	9.3
Istalef River	max	2.8	4.2	2.3	65.0	2.5	5.0	0.07	<.05	12.3
	mean	2.2	3.3	2.0	51.1	1.6	4.0	0.03	–	11.0
	median	2.3	3.5	2.1	49.7	1.8	4.4	<.05	<.05	11.0
	Number of samples	5	5	5	5	5	5	5	5	5
	min	5.6	8.7	2.5	64.0	8.5	15.5	0.07	<.05	8.2
Barik Ab River	max	70.8	132.0	8.0	360.6	149.0	192.0	0.30	0.18	26.7
	mean	26.6	48.9	4.6	198.6	58.5	82.5	0.16	–	13.5
	median	18.7	32.6	4.4	173.4	35.9	65.1	0.15	<.05	11.7
Panjsher	Number of samples	7	7	7	7	7	7	7	7	7
	min	5.5	6.6	3.3	82.0	11	17	0.05	<.05	6
Panjsher River at Sayad	max	14.1	22.8	5.7	162.0	38	33	0.10	<.05	8
	mean	9.7	14.3	4.4	118.7	22.7	24.4	0.07	–	7.7
	median	8.1	10.4	3.6	102.3	15.2	22.1	0.08	<.05	8.0
	Number of samples	1	1	1	1	1	1	1	1	1
	min	5.3	7.7	2.9	79.7	9.9	14.8	0.07	<.05	14.8
Panjsher River at Shukhi[1]	max	5.3	7.7	2.9	79.7	9.9	14.8	0.07	<.05	14.8
	mean	–	–	–	–	–	–	–	–	–
	median	–	–	–	–	–	–	–	–	–

1 - one value

Table 5. Summary statistics for trace-element concentrations by subbasin and region in the Kabul Basin, Afghanistan between May 2006 and July 2007 (Values in bold indicate maximum values that exceed World Health Organization guidelines).

[<, less than; ug/L, micrograms per liter; WHO, World Health Organization, 2006; --, not applicable]

Region	Statistic	As µg/L	Ba µg/L	Br µg/L	B µg/L	Cr µg/L	Co µg/L	Cu µg/L	Fe µg/L	Li µg/L
WHO guideline or proposed guideline		10	700	--		50	--	2,000	--	--
Groundwater Subbasin										
Central Kabul	Number of samples	13	13	13	13	13	13	13	13	13
	min	0.3	18	0.05	90	<1	<0.1	0.6	<20	<4
	max	8.9	223	2.43	**6,660**	24	2.33	9.6	90	518
	mean	2.4	71	0.49	1,172	6	0.52	2.3	8.5	128
	median	1.6	52	0.16	760	3	0.27	1.2	<20	104
Deh Sabz	Number of samples	3	3	3	3	3	3	3	3	3
	min	0.9	16	0.08	130	<1	0.25	0.7	<20	15
	max	4.4	34	0.29	420	9	0.35	2.5	<20	21
	mean	2.1	24	0.18	240	4	0.30	1.6	--	17
	median	1.1	22	0.17	170	2	0.31	1.6	<20	15
Eastern Front Souce Area	Number of samples	6	6	6	6	6	6	6	6	6
	min	0.4	8	<0.05	20	<1	0.06	0.3	<20	<1
	max	2.5	69	0.16	150	9	0.50	1.4	720	15
	mean	1.2	44	0.06	92	3	0.20	1.0	175	7
	median	0.9	44	<0.05	100	2	0.13	1.1	<20	6
Logar	Number of samples	4	4	4	4	4	4	4	4	4
	min	0.9	50	0.08	910	<1	0.12	0.7	<20	129
	max	1.9	104	0.23	**1,210**	7	0.30	1.8	<20	287
	mean	1.3	77	0.15	1,048	3	0.22	1.4	--	186
	median	1.1	67	0.13	980	1	0.19	1.3	<20	154
Paghman and Upper Kabul	Number of samples	6	6	6	6	6	6	6	6	6
	min	0.8	14	>.05	60	<1	0.14	0.6	<20	6
	max	3.8	103	0.19	**880**	7	0.37	5.7	<20	157
	mean	2.1	58	0.08	445	2	0.24	2.5	--	67
	median	2.2	49	0.06	190	<1	0.22	1.9	<20	33
Shomali	Number of samples	7	7	7	7	7	7	7	7	7
	min	0.3	28	<0.05	40	<1	0.11	0.3	<20	7
	max	1.9	123	0.22	**1,420**	8	0.42	1.7	40	329
	mean	0.9	72	0.06	386	4	0.26	0.8	8.6	77
	median	0.8	74	<0.05	70	3	0.27	0.7	<20	25
Western Front Source Area	Number of samples	6	4	4	4	4	4	6	4	4
	min	0.2	21	<.05	20	<1	0.07	0.3	<20	4
	max	1.1	46	0.1	50	4	0.49	1.4	<20	16
	mean	0.5	34	0.02	30	1	0.31	1.0	--	8
	median	0.4	29	<.05	20	<1	0.30	1.1	<20	5
Kabul Basin - all groundwater	Number of samples	47	43	47	43	43	43	43	43	43
	min	0.2	8	<.05	20	<1	0.06	0.3	<20	<1
	max	8.9	223	2.43	**6,660**	24	2.33	9.6	720	518
	mean	1.6	59	0.19	609	4	0.33	1.7	28	81
	median	1.1	49	0.11	170	2	0.27	1.2	<20	24

Table 5. Summary statistics for trace-element concentrations by subbasin and region in the Kabul Basin, Afghanistan between May 2006 and July 2007. Values in bold indicate maximum values that exceed World Health Organization guidelines.—Continued

[<, less than; ug/L, micrograms per liter; WHO, World Health Organization, 2006; --, not applicable]

Region	Statistic	Mn µg/L	Mo µg/L	Ni µg/L	Pb µg/L	Se µg/L	Sr µg/L	U µg/L	V µg/L	Zn µg/L
WHO guideline or proposed guideline		400	70	70	10	10	--	15	--	--
Groundwater Subbasin										
Central Kabul	Number of samples	13	13	13	13	13	13	13	13	13
	min	<1	0.8	<0.3	0.07	<1	516	2.60	0.7	4
	max	108	55.3	33.1	3.10	**38**	12,530	**31.80**	21.9	2030
	mean	11	8.0	11.5	0.48	6	2,276	10.36	8.0	297
	median	1	4.3	7.8	0.37	2	988	5.84	6.7	42
Deh Sabz	Number of samples	3	3	3	3	3	3	3	3	3
	min	<1	2.9	0.3	0.09	2	659	2.90	4.3	7
	max	4	8.5	4.5	1.90	7	1,310	11.60	14.2	48
	mean	2	5.4	1.7	0.74	4	925	6.97	9.9	21
	median	2	2.0	0.4	0.22	3	805	6.40	11.3	8
Eastern Front Souce Area	Number of samples	6	6	6	6	6	6	6	6	6
	min	<1	1.8	<0.1	0.38	<1	293	2.70	0.5	3
	max	21	3.7	1.9	**29.50**	3	978	9.20	6.7	134
	mean	5	2.6	0.8	11.51	1	701	6.05	3.1	41
	median	<1	2.3	0.6	2.95	1	659	5.30	1.7	9
Logar	Number of samples	4	4	4	4	4	4	4	4	4
	min	<1	1.7	0.3	0.16	1	865	5.10	1.1	5
	max	2	3.6	5.3	1.50	4	1,470	8.90	15.3	130
	mean	1	2.4	2.3	0.92	3	1,070	6.29	5.8	39
	median	<1	1.9	0.8	0.61	4	866	5.20	3.4	5
Paghman and Upper Kabul	Number of samples	6	6	6	6	6	6	6	6	6
	min	<1	1.2	0.1	0.10	<1	457	2.20	0.5	3
	max	3	4.4	13.1	4.00	3	1,120	14.90	9.5	511
	mean	2	2.5	6.0	1.09	1	693	7.40	3.2	92
	median	2	2.0	1.3	0.32	1	617	5.40	1.9	9
Shomali	Number of samples	7	7	7	7	7	7	7	7	7
	min	<1	0.6	0.1	0.08	<1	339	2.60	1.6	7
	max	17	4.0	0.9	7.12	2	2,120	**17.80**	16.1	165
	mean	4	2.2	0.5	1.21	0.5	882	6.96	7.3	34
	median	<1	2.4	0.5	0.19	<1	831	4.51	6.6	12
Western Front Source Area	Number of samples	4	4	4	4	4	4	4	4	4
	min	<1	0.5	0.2	0.14	<1	219	1.30	2.4	2
	max	4	2.1	1.5	2.00	1	1,600	5.30	9.7	540
	mean	1	1.3	0.8	0.90	--	655	3.18	5.9	188
	median	<1	1.2	0.2	0.44	<1	284	2.02	4.9	4
Kabul Basin - all groundwater	Number of samples	43	43	43	43	43	43	43	43	43
	min	<1	0.1	<.1	0.07	<1	219	1.30	0.5	2
	max	108	55.3	33.1	**29.50**	**38**	12,530	**31.80**	21.9	2030
	mean	5	4.2	4.9	2.32	3	1,251	7.51	6.3	136
	median	3	2.4	0.8	0.40	1	831	5.40	4.8	13

Table 5. Summary statistics for trace-element concentrations by subbasin and region in the Kabul Basin, Afghanistan between May 2006 and July 2007. Values in bold indicate maximum values that exceed World Health Organization guidelines.—Continued

[<, less than; ug/L, micrograms per liter; WHO, World Health Organization, 2006; --, not applicable]

Region	Statistic	As µg/L	Ba µg/L	Br µg/L	B µg/L	Cr µg/L	Co µg/L	Cu µg/L	Fe µg/L	Li µg/L
Surface Water Subbasin and River(s)										
Central Kabul	Number of samples	8	8	8	8	8	8	8	8	8
	min	2.2	14	0.05	180	<1	0.13	0	<20	29
Kabul River at Tangi-Gharu	max	8.3	57	0.15	730	3	1.74	4.3	1,690	124
	mean	3.9	39	0.06	494	2	1.04	1.6	211	86
	median	3.1	47	0.06	570	2	0.81	1.0	<20	79
Logar	Number of samples	7	7	7	7	7	7	7	7	7
	min	2.4	32	<0.05	380	<1	0.19	0.5	<20	69
Logar River	max	4.4	58	0.19	1,290	4	2.38	2.2	440	224
	mean	3.0	47	0.07	674	2	1.24	1.2	93	128
	median	2.7	51	0.07	640	2	1.11	1.0	<20	134
Paghman and Upper Kabul	Number of samples	8	8	8	8	8	8	8	8	7
	min	0.4	3	<.05	<20	<1	<.05	<.1	<20	<1
Paghman River	max	0.8	6	<.05	40	<1	2.07	1.0	154	4
	mean	0.6	5	--	15	--	0.62	0.5	32	2
	median	0.7	5	<.05	<20	<1	0.18	0.5	<20	1
	Number of samples	6	6	6	6	6	6	6	6	6
	min	1.8	8	<.05	<20	<1	0.11	<.1	<20	<20
Kabul River at Tangi Saidan	max	4.6	38	<.05	480	1	1.29	0.4	170	170
	mean	2.8	19	--	143	<1	0.64	0.3	32	30
	median	2.0	9	<.05	<20	<1	0.50	0.4	<20	<20
Shomali	Number of samples	7	7	7	7	7	7	7	7	7
	min	0.3	8	<.05	<20	<1	<.05	0.2	<20	6
Istalef River	max	0.6	20	<.05	20	<1	1.77	1.0	120	21
	mean	0.4	15	--	4	--	0.44	0.4	47	14
	median	0.4	14	<.05	<20	<1	0.26	0.3	20	12
	Number of samples	5	5	5	5	5	5	5	5	5
	min	1.2	19	<.05	80	<1	0.08	0.3	<20	21
Barik Ab River	max	2.8	110	0.18	1,110	6	1.72	4.6	2,280	109
	mean	1.9	50	0.05	418	1	0.70	1.4	462	51
	median	1.7	43	<.05	330	<1	0.41	0.6	<20	43
Panjsher	Number of samples	7	7	7	7	7	7	7	7	7
	min	0.9	20	<.05	40	<1	0.06	<.1	<20	30
Panjsher River at Sayad	max	1.8	44	<.05	400	<1	0.46	0.7	40	78
	mean	1.2	31	--	223	--	0.26	0.3	6	48
	median	1.1	25	<.05	200	<1	0.24	0.2	<20	47
	Number of samples	1	1	1	1	1	1	1	1	1
	min	0.8	79	<.05	120	<1	<.05	0.5	<20	21
Panjsher River at Shukhi	max	0.8	79	<.05	120	<1	<.05	0.5	<20	21
	mean	--	--	--	--	--	--	--	--	--
	median	--	--	--	--	--	--	--	--	--

Table 5. Summary statistics for trace-element concentrations by subbasin and region in the Kabul Basin, Afghanistan between May 2006 and July 2007. Values in bold indicate maximum values that exceed World Health Organization guidelines.—Continued

[<, less than; ug/L, micrograms per liter; WHO, World Health Organization, 2006; --, not applicable]

Region	Statistic	Mn µg/L	Mo µg/L	Ni µg/L	Pb µg/L	Se µg/L	Sr µg/L	U µg/L	V µg/L	Zn µg/L
Surface Water Subbasin and River(s)										
Central Kabul	Number of samples	8	8	8	8	8	8	8	8	8
	min	6	0.9	2.2	<.05	<1	202	1.34	1.6	<1
Kabul River at Tangi-Gharu	max	84	3.3	11.0	1.25	2	715	5.07	6.3	5
	mean	37	2.2	4.3	0.21	2	494	3.26	3.6	2
	median	25	2.6	3.3	<0.05	2	543	3.78	3.1	2
Logar	Number of samples	7	7	7	7	7	7	7	7	7
	min	3	2.2	2.8	<.05	<1	345	2.41	2.3	1
Logar River	max	44	3.7	7.6	0.57	3	1,460	8.78	4.9	9
	mean	18	3.0	4.1	0.15	2	643	4.55	3.2	3
	median	13	2.8	3.8	0.07	2	623	4.34	2.6	2
Paghman and Upper Kabul	Number of samples	8	8	8	8	8	8	8	8	8
	min	1	0.3	0.2	<.05	<1	32	0.06	1	<1
Paghman River	max	14	0.4	0.8	0.15	<1	59	0.20	2	12
	mean	5	0.4	0.5	0.06	--	47	0.11	0.9	3
	median	4	0.3	0.6	0.06	<1	49	0.09	0.6	2
	Number of samples	6	6	6	6	6	6	6	6	6
	min	5	0.6	1.5	0.03	<1	127	0.59	0.5	<1
Kabul River at Tangi Saidan	max	50	1.0	5.8	<.05	<1	397	1.93	2.1	2
	mean	24	0.7	3.2	0.03	--	235	1.12	1.2	1
	median	7	0.7	2.0	--	<1	161	0.66	0.6	<1
Shomali	Number of samples	7	7	7	7	7	7	7	7	7
	min	1	0.4	0.2	<.05	<1	38	0.24	2.5	<1
Istalef River	max	18	0.8	0.9	0.39	<1	480	0.66	3.9	9
	mean	8	0.6	0.6	0.10	--	131	0.47	3.4	3
	median	6	0.6	0.6	0.07	<1	82	0.50	3.5	3
	Number of samples	5	5	5	5	5	5	5	5	5
	min	8	0.9	0.7	<.05	<1	145	1.40	2.6	<1
Barik Ab River	max	64	3.0	6.2	1.67	3	1,920	**17.50**	10.9	8
	mean	24	2.0	2.4	0.39	1	721	6.47	5.7	2
	median	14	2.0	1.7	0.07	1	578	4.78	5.3	<1
Panjsher	Number of samples	7	7	7	7	7	7	7	7	7
	min	2	0.6	0.5	<.05	<1	126	0.83	0.4	<1
Panjsher River at Sayad	max	9	1.1	1.2	0.29	<1	328	2.37	1.3	4
	mean	5	0.8	1.0	0.08	--	214	1.62	0.7	2
	median	4	0.8	1.0	<.05	<1	153	1.59	0.6	1
	Number of samples	1	1	1	1	1	1	1	1	1
	min	<1	0.8	0.3	<.05	<1	128	0.91	0.5	21
Panjsher River at Shukhi	max	<1	0.8	0.3	<.05	<1	128	0.91	0.5	21
	mean	--	--	--	--	--	--	--	--	--
	median	--	--	--	--	--	--	--	--	--

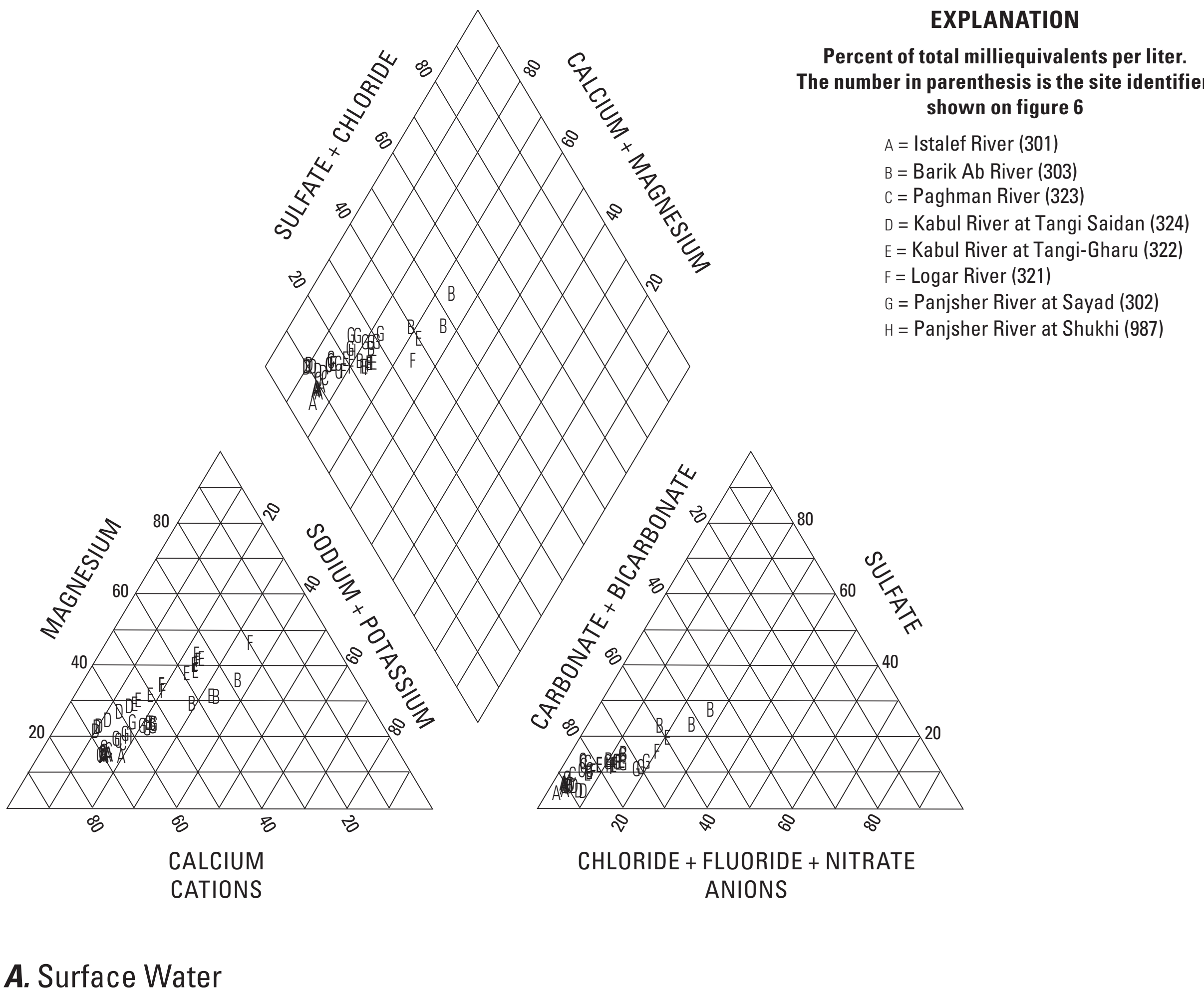
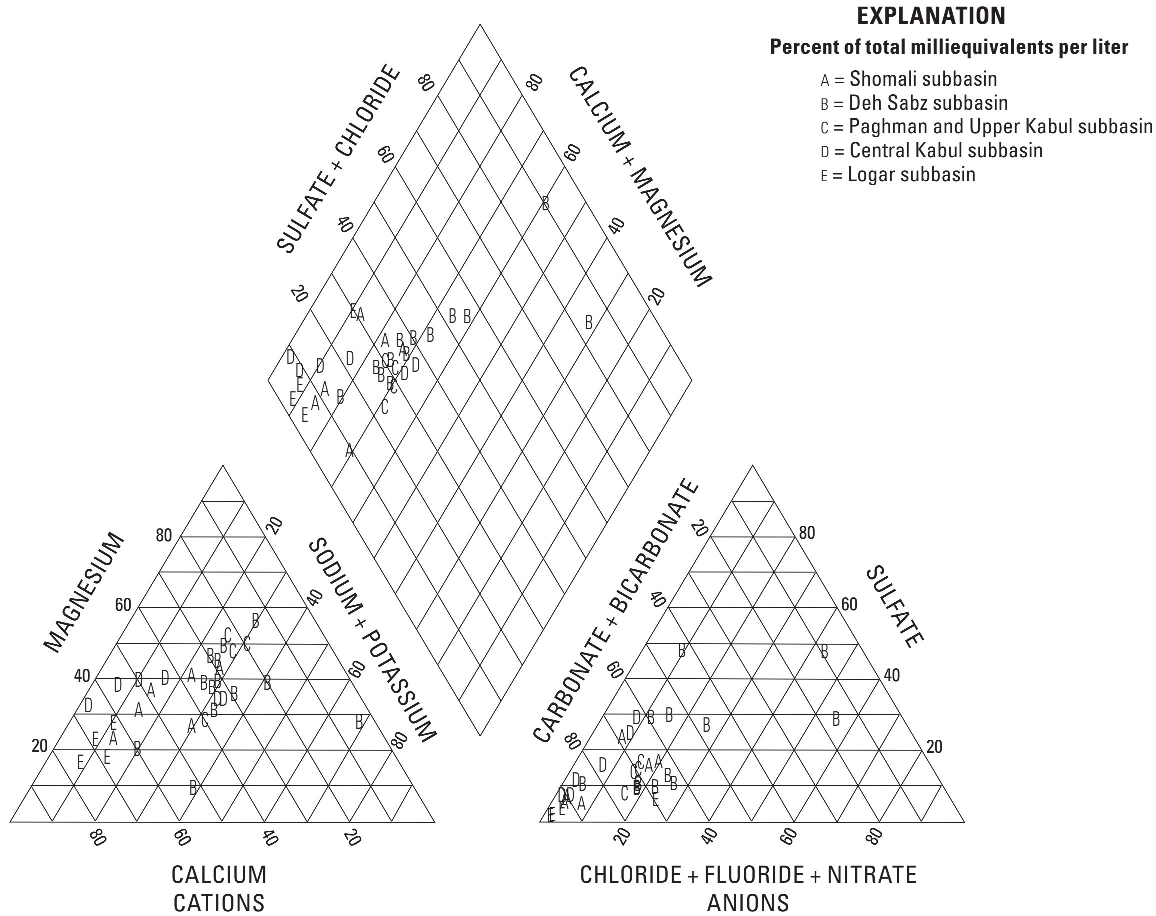


Figure 18. Trilinear diagrams of (A) surface-water and (B) groundwater quality in the Kabul Basin, Afghanistan, 2006–07.



B. Groundwater

Figure 18. Continued.

Surface Water

In 2006 and 2007, samples were collected from eight rivers in the Kabul Basin and were analyzed for physical properties, bacteria, major ions, and trace elements (tables 4 and 5, fig. 18).

The specific conductance of surface water measured in the Kabul Basin ranged from a minimum of 67 µS/cm, at Paghman River to 1,497 µS/cm at Barik Ab River (table 4). The median specific conductances by subbasin ranged from 111 µS/cm in the Paghman River (Upper Kabul/Paghman subbasin) to 742 µS/cm in the Kabul River at Tang-i-Gharu (Central Kabul subbasin). Specific conductances (fig. 19) were low in streams flowing into the Kabul Basin from adjacent upland areas, such as the Istalef and Paghman Rivers (medians of 140 and 111 µS/cm respectively; table 4).

Nitrate concentrations (fig. 20) measured in the Kabul Basin ranged from 0.4 mg/L in the Paghman River to 5.9 mg/L at the Barik Ab River. Median concentrations by subbasin ranged from 1.0 mg/L at the Paghman River to 2.9 mg/L in the Kabul River at Tang-i-Gharu (table 4). Total coliform (fig. 21) was detected in all streams sampled and ranged from 116 in the Paghman River to at least 2,420 colonies per 100 mL in the Barak Ab River and Kabul River at Tang-i-Gharu. *E. coli* (fig. 22) was detected in water samples at the 7 surface-water sites tested (table 4). *E. coli* colonies in excess of 2,420 per 100 mL were detected in the Istalef River, the Kabul River at Tang-i-Gharu, and the Barik Ab River (fig. 22).

Surface-water quality was predominately of the calcium-bicarbonate type in the Kabul Basin, and sample compositions were generally tightly clustered in the trilinear plot with little variation (fig. 18A). More variation was observed in the Barik Ab River, Logar River, and the Kabul River at Tang-i-Gharu (fig. 18A) with samples containing more ions, particularly chloride and sulfate. At these sites, concentrations of chemical constituents were lower during spring-melt high-flow periods and higher during low-flow periods than at other times of the year.

Groundwater

As observed in data previously collected by the USGS and AGS (Broshears and others, 2005), groundwater quality in the Kabul Basin varied widely. The major-ion chemistry of Kabul Basin groundwater was generally of the calcium-magnesium bicarbonate type (fig. 18B). Some groundwater sampled in the Central Kabul and Deh Sabz subbasins and in the Paghman and Upper Kabul subbasin (one sample only) was of the sulfate-chloride type, and other samples collected in the same subbasins were of intermediate compositions (fig. 18B). Some chemical concentrations also were high in the Logar subbasin, probably because of proximity to urban areas, as was true for the Central Kabul subbasin. These differing chemistries indicated possible influences by anthropogenic or industrial contamination, poor well construction, possible dissolution of rocks containing gypsum, or increased concentrations of ions caused by evapotranspiration processes as suggested by Broshears and others (2005), especially in the Central Kabul subbasin. In the Deh Sabz subbasin, groundwater appears to have evolved from the calcium-magnesium bicarbonate type to a sulfate-chloride or sodium type (fig. 18B).

The median values of water-quality parameters in groundwater in the Central Kabul subbasin (fig. 1) were generally higher than in the other basins (tables 4 and 5). Parameters that appeared to have higher median values in the Central Kabul subbasin included specific conductance, and concentrations of hardness measured as alkalinity, nitrate plus nitrite, bromide, magnesium, sodium, potassium, chloride, arsenic, boron, nickel, and zinc. Additionally, concentrations of four elements—fluoride, boron, selenium and uranium—in the Central Kabul subbasin exceeded World Health Organization (WHO) guidelines. Uranium concentrations were higher than 5 µg/L in much of the Kabul Basin and higher than the WHO guideline of 15 µg/L in three samples.

Specific conductances and concentrations of dissolved oxygen and nitrate as N in the Kabul Basin (fig. 19) generally indicated the effects of urbanization. Median values of specific conductances in groundwater specific ranged from 51 in the Eastern Front Source Area (fig. 1) to 1,177 µS/cm in the Central Kabul subbasin (table 4). Overall, the conditions in the aquifer were slightly oxic with dissolved oxygen concentrations in the subbasins ranging from 0.1 to 1.9 mg/L as O_2 and a median value of 0.1 mg/L. The operation of some production pumps, however, may have increased the oxygen content of water samples. Median nitrate concentrations as N in the subbasins ranged from 1.2 mg/L in the Eastern Front Source Area to 6.7 mg/L in Central Kabul. Elevated nitrate concentrations in the Kabul Basin (fig. 20) also generally indicated the effects of urbanization. The median nitrate concentration for the entire Kabul Basin was 3.3 mg/L as N (table 4). The highest nitrate concentration (40.21 mg/L as N) was observed in water from one well in the Western Front Source Area. Concentrations of nitrate in groundwater from the Central Kabul and Paghman and Upper Kabul (median of 3.2 mg/L) subbasins were greater than concentrations measured in samples collected elsewhere in the Kabul Basin; most of the water samples with nitrate concentrations as N exceeding 10 mg/L were collected from the Central Kabul and Paghman and Upper Kabul subbasins (fig. 20).

Total coliform bacteria were detected in nearly all of the groundwater samples. The counts were more than 2,420 colonies per 100 mL in some wells (table 4). More than 100 colonies per 100 mL were detected in samples from all of the subbasins with the exception of the Eastern Front Source Area (4 colonies per 100 mL). *E. coli* was detected in 66 of 68 samples collected (table 4). Water from well 8 located in the Deh Sabz subbasin, with more than 2,420 colonies per 100 mL total coliform, had the highest reported concentration of colonies of *E. coli* (461 colonies per 100 mL); however, detections of *E. coli* appeared to be randomly distributed throughout the basin.

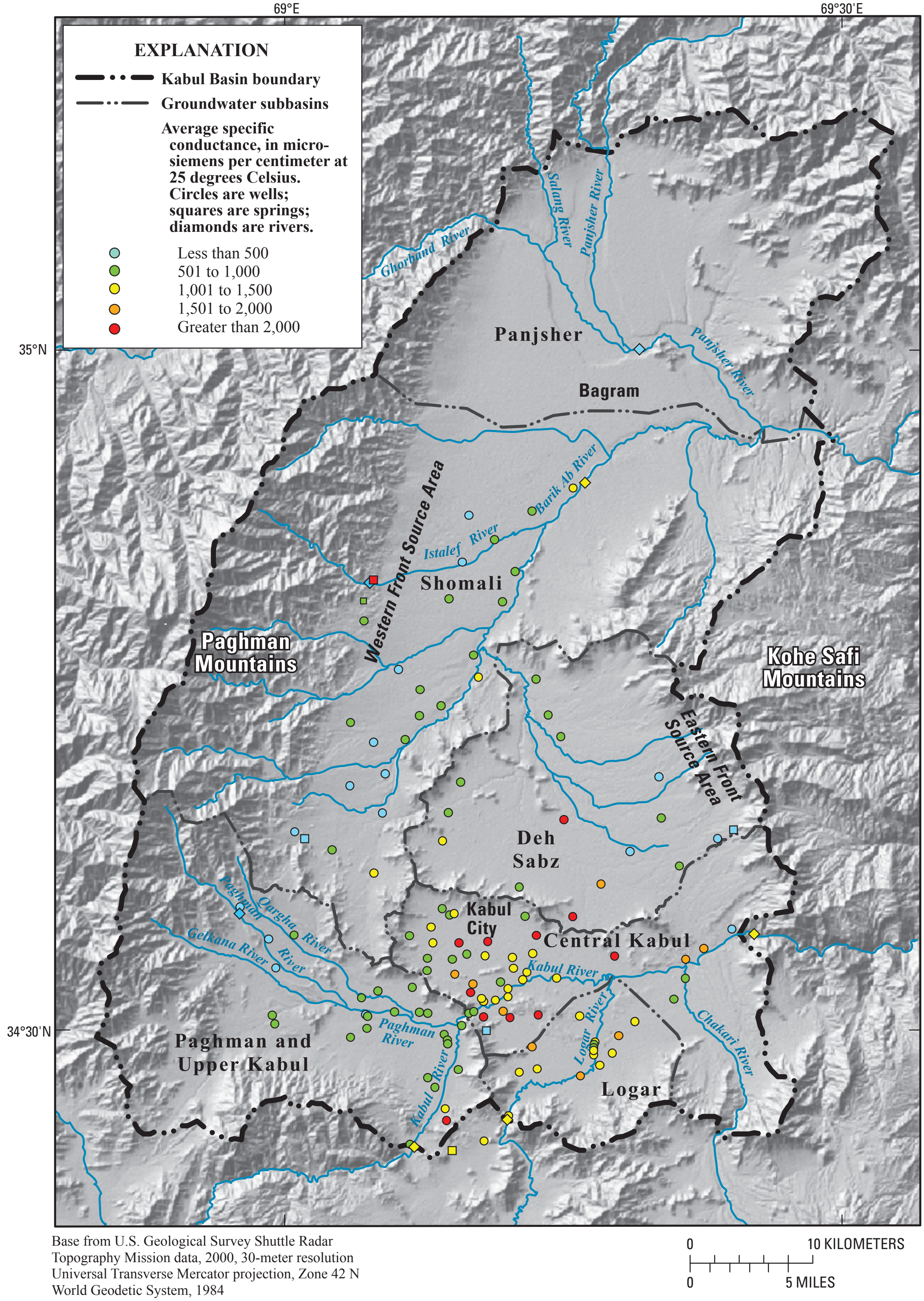


Figure 19. Specific conductance of water in the Kabul Basin, Afghanistan, 2006–07.

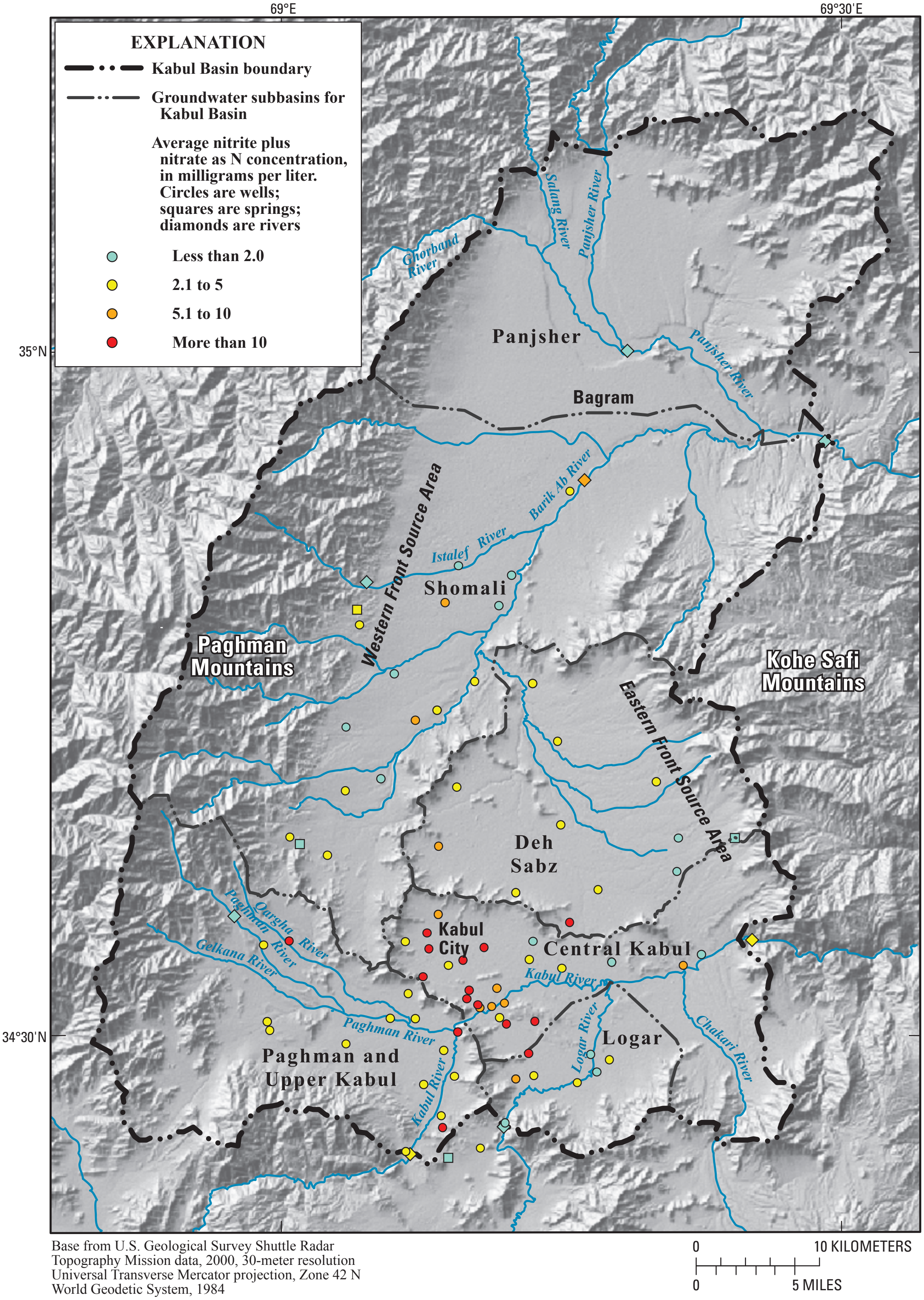


Figure 20. Nitrate concentrations in water in the Kabul Basin, Afghanistan, 2006–07.

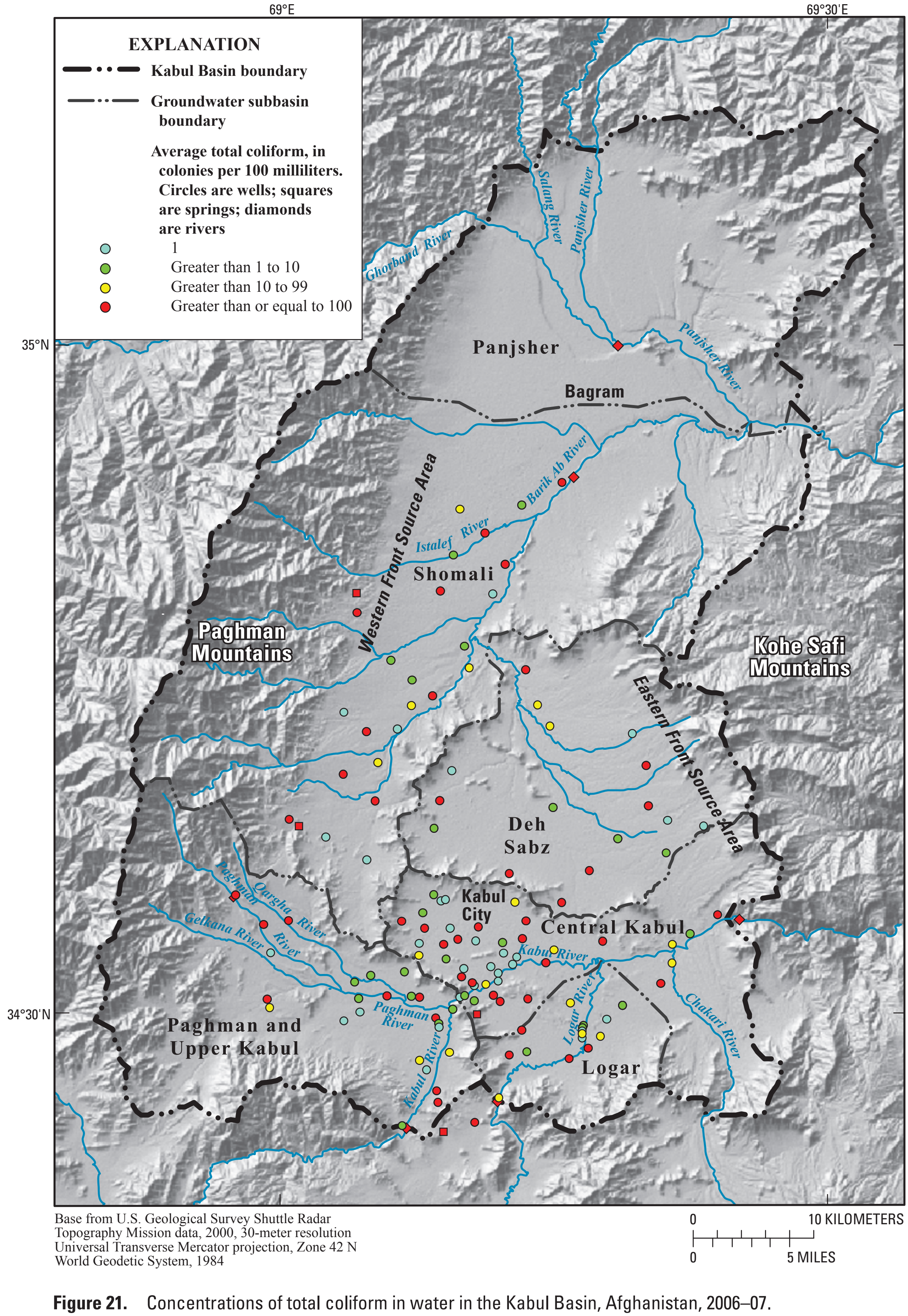


Figure 21. Concentrations of total coliform in water in the Kabul Basin, Afghanistan, 2006–07.

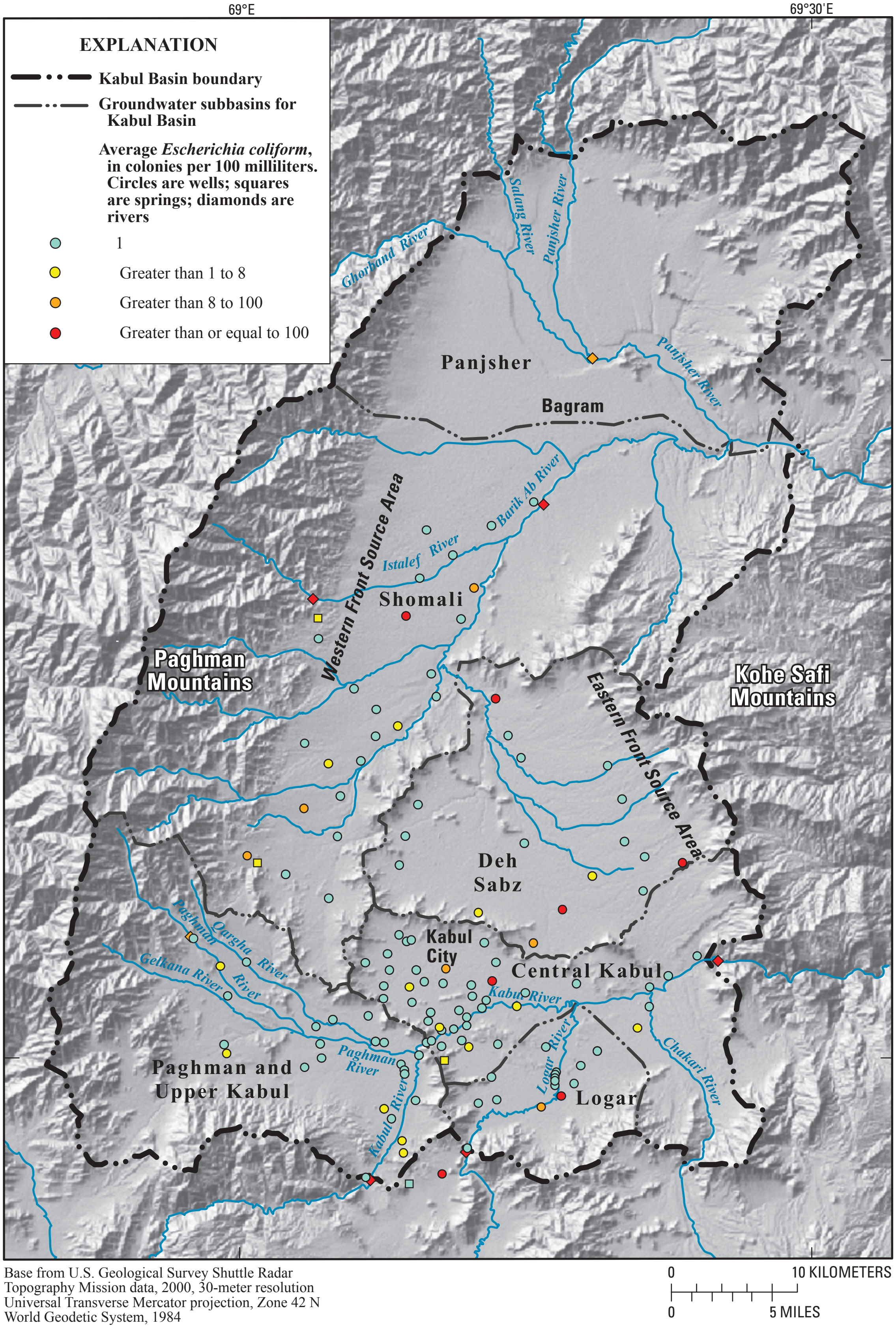


Figure 22. Concentrations of *Escherichia coli* in water in the Kabul Basin, Afghanistan, 2006–07.

Four groundwater exceedances with respect to WHO (2006) drinking-water guidelines were noted:

1. The guideline of less than 1 colony per 100 mL for *E. coli* was exceeded in 66 of 68 of the samples (97 percent).
2. The guideline of 50 mg/L as N for nitrate was not exceeded. Concentrations in 7 of 43 samples (16 percent), however, were greater than 10 mg/L.
3. The guideline of 10 µg/L for arsenic was not exceeded in any of the 47 samples and was greater than 5 mg/L only in 1 sample.
4. The guideline of 10 µg/L for lead was exceeded in 3 of 43 (7 percent) of the samples, all in the Eastern Front Source Area.
5. The guideline of 10 µg/L for selenium was exceeded in 1 of the 43 samples.
6. The guideline of 15 µg/L for uranium was exceeded in 3 of the 43 samples; concentrations in 26 of the 43 samples were greater than 5 µg/L.

As Broshears and others (2005) found, contamination of drinking-water sources by anthropogenic activities, such as the introduction of untreated wastewater and nitrate contamination from fertilizer applications, remains an important concern to the population of the Kabul Basin.

Chemical and Isotopic Analysis

Chemical and isotopic analyses of waters in the Kabul Basin focused on concentrations of stable hydrogen and oxygen isotopes, chlorofluorocarbons, and tritium in groundwater and surface water; mass concentration ratios; geochemical reactions; and solute origins.

Stable Hydrogen and Oxygen Isotopes in Groundwater and Surface Water

Previous stable isotope and tritium measurements in precipitation were made by the International Atomic Energy Agency (IAEA), which collected and analyzed integrated precipitation samples from the city of Kabul monthly between January 1962 and September 1989; although data for many months are missing (International Atomic Energy Agency, 2004), stable oxygen and hydrogen isotopic data for 86 monthly samples and 123 monthly composite values of tritium in precipitation are in the database composed by the IAEA and the World Meteorological Organization for Kabul.

The concentrations of the stable hydrogen isotopes (^{1}H and ^{2}H) and oxygen isotopes (^{16}O and ^{18}O) in precipitation commonly vary owing to differences in latitude, season, and other factors. The unique signatures of stable hydrogen and oxygen isotopes can be used to differentiate among surface waters and groundwaters recharged by these surface waters. In this study, 80 groundwater, 4 karez, 7 spring, and 76 surface-water samples were collected and analyzed for stable hydrogen and oxygen isotopic composition. Between early December 2006 and mid-July 2007, surface-water samples were collected at seven sites. The details of the analytical methods and the measurement results are discussed in detail in Appendix 11.

In the Kabul Basin, surface waters were assigned to four groups based on their stable hydrogen and oxygen isotopic composition (fig. 23). The samples lowest in ^{2}H and ^{18}O were those of the Panjsher River, this isotopic profile reflects meltwater from snow in the high-altitude source area extending to the Khyber Pass in Pakistan. The lowest ^{2}H and ^{18}O concentrations, which measured in late June, presumably reflect the highest fraction of snow meltwater. Samples from the Istalef River at Istalef and the Paghman River at Paghman surface-water sites were most enriched in ^{2}H and ^{18}O; this result is consistent with the relatively low-altitude source areas for these rivers in the foothills west of the Kabul Basin (fig. 23, fig. 1). None of the surface-water bodies studied are affected by significant evaporation.

Stable isotopic composition of surface waters in the Kabul Basin

Surface waters were assigned to four groups based on isotopic compositions:

1. The waters of the Istalef and the Paghman Rivers are isotopically indistinguishable from one another, reflect a precipitation source in an arid environment with the lowest relative humidity (approximately 70 percent), and are indistinguishable from precipitation collected by the IAEA at Kabul between 1962 and 1989.
2. The Kabul River at Tang-i-Saidan and the Barik Ab River near Bagram are hydrologically distinct (have different sources) but very similar isotopically.
3. The Kabul River at Tang-i-Gharu and the Logar River samples form a third isotopic grouping, but they are not the same water hydrologically. Because the Kabul River at Tang-i-Saidan, the Logar River, and the Paghman River supply water to the Kabul River at Tang-i-Gharu, the isotopic compositions of samples collected at this site are determined by the isotopic compositions and mass balances of the waters from the three sources.
4. Panjsher River samples by themselves form the fourth group.

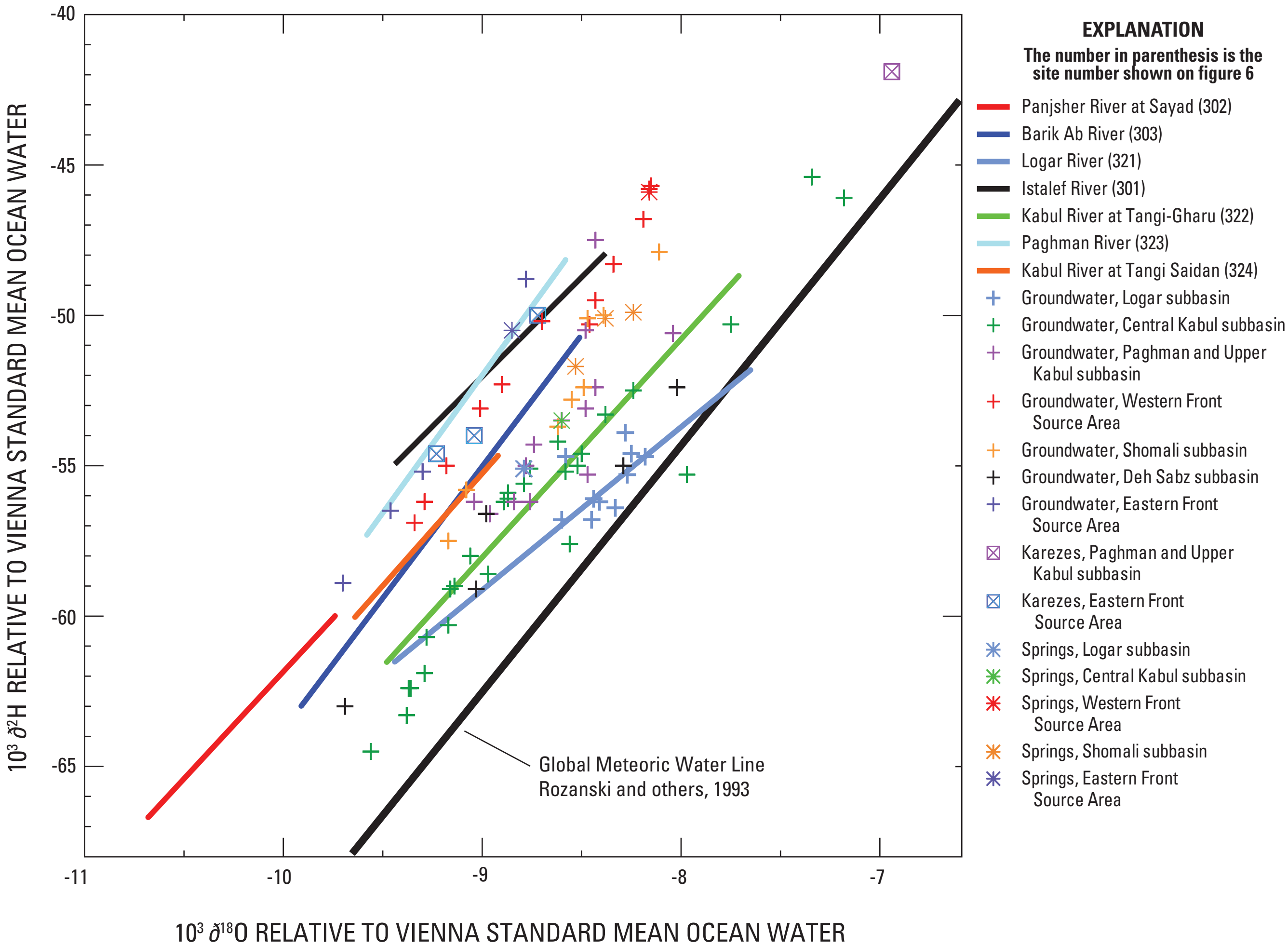


Figure 23. The hydrogen versus oxygen isotopic composition, relative to Vienna Standard Mean Ocean Water, of surface water, groundwater, and water from karezes and springs in the Kabul Basin, Afghanistan.

The isotopic compositions of water sampled from groundwater wells, karezes, and springs are plotted on figure 23, and with few exceptions, the points for each site plot near one of the four isotopically distinguishable surface-water sources discussed above. Water sampled from groundwater wells, karezes, and springs in the subbasins can be assigned to seven groundwater-source areas on the basis of isotopic and chemical analysis: Western Front Source Area, Shomali subbasin, Deh Sabz subbasin, Eastern Front Source Area, Paghman and Upper Kabul subbasin, Central Kabul subbasin, and Logar subbasin. Groundwaters in the Western Front Source Area area in the Shomali subbasin and the Eastern Front Source Area in the Deh Sabz subbasin differ from groundwater elsewhere in their respective subbasins on the basis of stable hydrogen and oxygen isotopes. Some of the groundwaters had chloride mass concentrations as high as 1,650 mg/L, a factor of 10 to 50 times higher than that in the presumed surface source waters. Had these chloride enrichments been caused by evaporative concentration, one would expect very substantial enrichments in ^{2}H and ^{18}O. No such enrichments were found; therefore, another mechanism must be responsible for the elevated chloride content. (See the subsection titled "Mass Concentration Ratios, Geochemical Reactions, and Solute Origins.")

Stable isotope evidence for groundwater regions of the Kabul Basin

In this arid environment, none of the isotopic compositions of the groundwater samples indicated substantial evaporation except for samples collected from a single karez. The groundwater, karez, and spring sites can be assigned on the basis of their stable isotopic composition to seven groundwater areas (fig. 1):

1. Western Front Source Area. This groundwater appeared to be runoff such as rain and snow meltwater from the Paghman Mountains. The relative humidity of the source area is among the lowest in the Kabul Basin (approximately 70 percent).
2. Shomali subbasin. The isotopic composition of this groundwater indicated that it was not recharged from modern Istalef River water, but from a source where the relative humidity was higher than 70 percent.
3. Deh Sabz subbasin. The stable hydrogen and oxygen isotopic compositions of these groundwater samples are similar to those of samples from the Kabul River at Tang-i-Gharu and Logar River.
4. Eastern Front Source Area. This water is similar in isotopic composition to that of the Western Front Source Area, possibly because the source of recharge in both areas is the adjacent mountains. The relative humidity of the source area is among the lowest in the region (approximately 70 percent).
5. Paghman and Upper Kabul subbasin. Except for samples collected from two wells, this groundwater had stable hydrogen and oxygen isotopic compositions that were similar, in geographic accord, to those of surface-water samples collected from the Kabul River at Tang-i-Gharu, the presumed source.
6. Central Kabul subbasin. This groundwater also had stable hydrogen and oxygen isotopic compositions that were very similar, in geographic accord, to those of surface-water samples collected from the Kabul River at Tang-i-Gharu.
7. Logar subbasin. This groundwater appeared to be derived from the Logar River on the basis of the similar stable hydrogen and oxygen isotopic compositions of samples collected from the two sources.

Mass Concentration Ratios, Geochemical Reactions, and Solute Origins

Chloride mass concentrations were nearly 4,200 mg/L in groundwater in the Central Kabul subbasin of the Kabul Basin. Several hypotheses for the origin of the high chloride concentrations were considered: evaporation of surface water (discussed in the preceding section on stable isotope data), geochemical water-rock reactions, dissolution of salts precipitated from evaporation of surface water, upward leakage of (presumed) deep saline water, and water uptake by vegetation (transpiration). These hypotheses are discussed in detail in Appendix 12. Table 6 summarizes average solute concentrations, stable isotope data, and tritium data for groundwater from the seven groundwater-source regions (fig. 1) and compares average solute concentrations in groundwater to average concentrations surface water in each region.

Mass concentration ratios of some of the dissolved solutes to dissolved chloride in groundwater were similar to the same ratios in surface-water samples from particular subbasins. This similarity is demonstrated most consistently in the data for dissolved sodium and sulfate, and to a lesser extent in the data for dissolved magnesium (fig. 24). Ratios in groundwater sampled in other subbasins were less similar to the surface-water ratios, and those differences can be attributed to common water-rock reactions, including calcite precipitation or removal or addition of Ca and HCO_3 by dissolution; cation exchange (Ca and Mg uptake and release of Na); gypsum dissolution (addition of Ca and SO_4); and sulfate reduction (removal of SO_4). The similarity of the mass ratios of the more conservative solutes (Na, SO_4, Mg) to chloride in groundwater to the same ratios for surface water, together with the isotope data, suggests a surface-water source for many of the groundwater samples. Plots that show solute

Table 6. Summary of average selected water-quality parameters measured in samples from groundwater and surface water from the Kabul Basin by groundwater region, 2004-2007.

[m, meters; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; Alk, titration alkalinity; δ^2H, delta deuterium; $\delta^{18}O$, delta oxygen-18; TU, Tritium unit; na, not applicable; <, less than]

Region	No.	Well depth (m)	Sample water level (m)	Water temp. (°C)	Specific conduc - tance (µS/cm)	pH field	O_2, mgL	Total coli	*E. coli*	NO_3 N, mg/L	Ca, mg/L	Mg, mg/L	Na, mg/L	K, mg/L	Alk, mg/L as $CaCO_3$	Cl, mg/L
Ground water																
Central Kabul	66	52.8	14.5	16.9	2,210	7.6	5.9	391	9	10.3	91.6	112.0	265.0	10.3	309.5	409.6
Deh Sabz	19	54.4	17.9	17.1	1,152	7.5	7.2	469	43	4.1	63.8	42.9	81.5	3.3	213.4	81.5
Eastern Front Source Area	11	114.1	25.0	17.3	496	7.9	4.1	2	45	1.8	51.2	26.3	27.5	1.8	217.0	12.1
Logar	27	39.5	7.9	14.8	1,275	7.7	5.3	297	18	4.1	52.5	88.3	102.9	6.5	432.8	103.6
Paghman and Upper Kabul	36	50.7	14.6	15.0	734	7.6	9.1	128	9	4.9	98.1	36.3	60.0	4.3	248.3	38.6
Shomali	26	66.9	16.4	15.1	717	7.4	8.7	348	8	3.4	74.1	27.5	31.4	4.5	260.1	27.7
Western Front Source Area	21	38.3	12.0	14.5	498	7.4	6.7	604	11	7.1	65.8	15.9	11.0	3.0	200.2	11.8
Surface water																
Central Kabul	12	na	na	11.2	662	8.8	nd	2,420	2,420	3.0	52.0	29.1	34.5	4.2	228.5	35.0
Logar	11	na	na	8.4	661	8.7	nd	1,120	162	2.1	51.7	37.5	42.3	3.9	266.1	40.5
Paghman and Upper Kabul	22	na	na	9.0	294	8.6	nd	765	215	1.6	29.3	6.5	6.1	1.5	94.9	5.5
Shomali [1]	34	na	na	9.1	323	8.5	nd	1,168	1,252	1.6	32.8	11.1	18.8	3.5	104.1	23.6

Region	No.	SO_4, mg/L	F, mg/L	Br, mg/L	SiO_2, mg/L	As, µg/L	B, µg/L	Li, µg/L	Se, µg/L	Sr, µg/L	U, µg/L	V, µg/L	Zn, µg/L	δ^2H x 1,000	$\delta^{18}O$ x 1,000	Trit-ium, TU
Ground water																
Central Kabul	66	363.4	0.42	0.83	27.3	2.2	1,217	142	4.6	2,143	12.2	7.1	227	-56.5	-8.7	9.5
Deh Sabz	19	163.7	0.41	0.36	26.4	1.6	495	30	3.1	1,503	8.9	7.7	116	-57.2	-8.8	7.6
Eastern Front Source Area	11	54.9	0.25	0.11	15.8	1.3	75	9	1.4	794	5.2	3.3	39	-53.6	-9.1	9.0
Logar	27	128.2	0.47	0.30	26.5	3.1	1,444	219	4.4	1,452	9.8	4.5	169	-55.5	-8.4	10.8
Paghman and Upper Kabul	36	44.9	0.25	0.13	22.1	1.7	398	55	4.4	1,386	5.6	3.0	178	-53.3	-8.6	12.4
Shomali	26	44.9	0.25	0.12	24.2	0.8	217	40	1.0	834	6.8	6.6	283	-52.0	-8.5	13.4
Western Front Source Area	21	8.3	0.19	0.06	22.7	0.5	57	13	0.3	545	3.0	4.7	125	-50.5	-8.6	12.7
Surface water																
Central Kabul	12	49.4	0.22	0.10	14.3	3.9	494	86	2.0	494	3.3	3.6	2.7	-57.3	-8.9	8.2
Logar	11	53.9	0.28	0.10	15.4	3.0	674	128	1.8	643	4.6	3.2	3.1	-59.7	-9.1	7.1
Paghman and Upper Kabul	22	8.7	0.10	0.10	9.4	1.6	140	17	<1	128	0.5	1.0	3.0	-54.7	-9.1	9.4
Shomali [1]	34	31.3	0.10	0.11	10.3	1.1	271	35	2.0	307	2.4	2.9	5.3	-56.3	-9.3	10.1

[1] Panjsher River samples included with Shomali Basin samples for this analysis.

ratios for calcium and bicarbonate (appendix 12) indicate some departures from the ratios for surface water. The patterns of the Na, SO_4, and Mg solute ratios relative to chloride in groundwater (red symbols on fig. 24 for wells with a depth range of 5 to 185 m and a median depth of 48 m) and surface-water samples are similar to those for samples from relatively deep waters of the Kabul Basin (green cross symbols on fig. 24 for the former USSR PASSPORT wells with a depth range of 172 to 654 m and a median depth of 267 m) and for one sample from the recently drilled Japan International Cooperation Agency (JICA) Test Well 1 (purple point on fig. 24 for a well with total depth 640 m) (Japan International Cooperation Agency, 2007a, b). The similarity in solute ratios between waters from deep and shallow wells and surface waters suggests that infiltrated surface water has reached depths of at least 650 m in the Kabul Basin, presumably on a time scale of thousands of years. Departures in solute ratios in groundwater from those observed in surface water can be attributed to common water-rock reactions.

The chemical, stable isotope, and environmental-tracer data indicate that the infiltration of surface water is the most likely source of recharge for most of the groundwater in the Kabul Basin. In irrigated agricultural areas where pumps are used to deliver irrigation water, groundwater may be moved through multiple cycles of pumping, irrigation, and return flow to the water table; these cycles further elevate the dissolved solute concentration. The average solute mass concentrations in groundwater are increased during irrigation and infiltration cycles relative to those of local surface water by factors of 3.3, 1.9, 2.5, and 2.2 for the Central Kabul, Logar, Paghman and Upper Kabul, and Shomali subbasins, respectively.

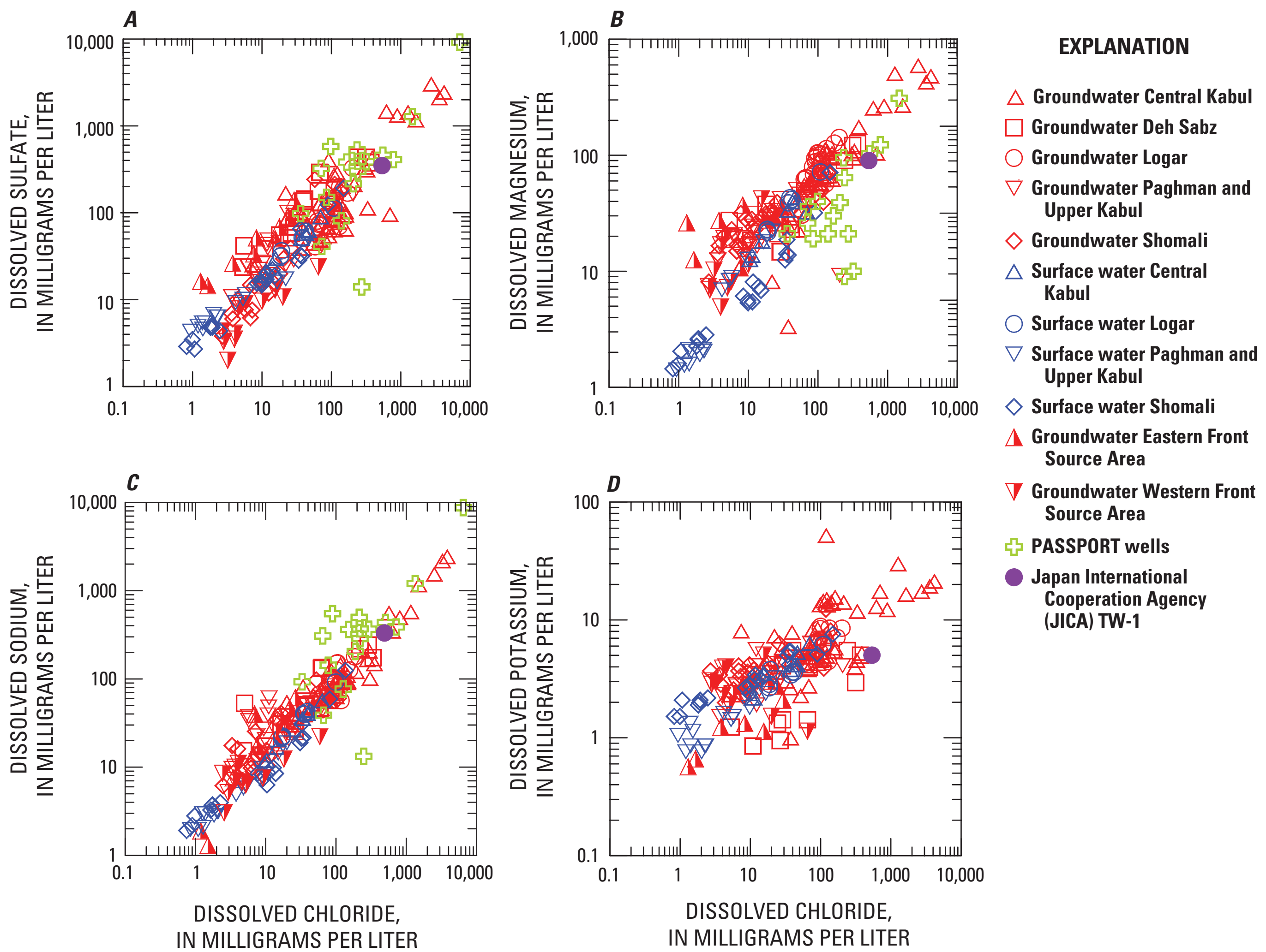


Figure 24. Mass concentrations of dissolved (A) sulfate, (B) magnesium, (C) sodium, and (D) potassium in surface water (blue), shallow groundwater (red), and deep groundwater (green and purple) from the Kabul Basin as a function of dissolved chloride mass concentration. The concentrations in water sampled from the PASSPORT wells in (C) are for sodium and potassium combined; concentrations of potassium were not determined separately for water from the PASSPORT wells.

Origin of dissolved solutes in the Kabul Basin groundwater

1. The average ratios of concentrations of some of the dissolved major solutes (particularly Na and SO_4) to chloride are similar to the corresponding average ratios in surface water; this similarity suggests that surface water is the predominant source for most of the groundwater sampled in the basin to depths of at least 650 m.
2. Variations in the concentration ratios for other solutes (particularly Ca, HCO_3, and to some extent Mg) indicate a relatively small effect by common water-rock reactions, including calcite precipitation and cation exchange in shallow groundwater.
3. Higher ratios of silica to chloride in groundwater relative to surface water indicate dissolution of primary silicate minerals or other siliciclastics that are abundant in the rocks and alluvial deposits of the Kabul Basin.
4. Arsenic appears to be partially removed by geochemical processes in the groundwater environment—probably by sorption on iron-manganese oxyhydroxides.
5. CFCs and tritium were detected in all of the 35 groundwater samples analyzed for CFCs and tritium, even in samples with chloride mass concentrations greater than 2,000 mg/L; this result indicates a young (post-1950s) source of water recharging the shallow groundwater system.
6. Solute concentrations in many groundwater samples exceeded those measured in surface water by factors of as much as 100 or more. Because there is no evaporative signal in the stable isotope data, the high solute content is attributed to extraction of water by vegetation (transpiration) along the rivers and surface-water drainage areas and near irrigated crop land, where plant-root systems can reach the water table. Transpiration removes water without altering the stable isotopic composition of the residual water; thus, the solutes are concentrated without a detectable shift in stable isotopic composition.

Chlorofluorocarbons and Tritium in Groundwater and Surface Water

Mass fractions (pg/kg) of CFC-11, CFC-12, and CFC-113 were measured to obtain information on groundwater ages (International Atomic Energy Agency, 2006). Groundwater was sampled from 35 wells between May 2006 and June 2007; from 6 springs in May and June 2006; and from 14 surface-water sites in February and June 2007 (fig. 6). CFCs also were determined in 6 air samples, all from the Kabul region. Tritium, ^3H (^3H concentration greater than 0.5 TU, where 1 TU is $n(^3H)$ / $n(^1H)$ of 10^{-18} mol/mol), was determined in 45 water samples from wells and springs and in 7 surface-water samples. Additional tritium measurements completed late in this study are included in appendix 10; these data are consistent with the rest of the tritium collected in this study. The presence of tritium indicates waters that are post-1955 in age or waters that are mixtures of old (pre-1955) water with post-1955 water. The presence of CFC-11 or CFC-12 indicates waters that are approximately post-1945 in age or are mixtures of old (pre-1945) water with post-1945 water, and the presence of CFC-113 indicates post-1957 water, or mixtures of old (pre-1957) water with post-1957 water. All of the water samples analyzed (from the upper aquifer, springs, and surface water) contained CFCs and tritium and can be considered young water. Old water is water recharged pre 1945, young water was recharged post-1945, and modern water is water of a few years in age or residence time. The CFC and tritium data are summarized in Appendix 13.

On the basis of stable isotope and mass-concentration-ratio data (above), it was concluded that much of the groundwater sampled as a part of this study had infiltrated from rivers and streams. The CFC concentrations in groundwater recharge will be equal to the respective concentrations in surface water at time of recharge. Depending on local land-use activities at time of recharge, the streams and irrigation canals may have contained additional anthropogenic sources of CFCs, leading to a young bias in the interpreted age of the recharged groundwater. Multiple cycles of recharge and discharge of water to and from groundwater reservoirs near streams and canals can be driven by alternating low- and high-flow conditions. These processes have likely affected both tritium and CFC concentrations in Kabul Basin groundwater.

The median mass fractions of CFC-11, CFC-12 and CFC-113 in the 41 groundwater samples (35 wells and 6 springs) were 309, 221, and 39 pg/kg, respectively, corresponding to volume fractions of 150, 474, and 45 parts per trillion (ppt). In unmixed samples (samples not diluted by mixing with old water), these median CFC volume fractions correspond to median groundwater ages of 30, 21, and 21 years, respectively. The lowest CFC volume fractions in any one groundwater sample (well 54) were 64, 165, and 20 ppt for CFC-11, CFC-12, and CFC-113, corresponding to piston-flow ages of 36, 35, and 28 years, respectively. Because most of the samples are pumped from open boreholes, the CFC mass fractions are measured in mixed water, and thus the interpreted age reflects this mixture. In this case, the age is referred to as the median or apparent age. (See appendix 13 for further discussion of the interpretation of ages based on environmental-tracer data collected from samples of mixed water).

The median tritium concentration in the groundwater samples was 11.0 TU. It is estimated that modern precipitation in the Kabul Basin contains about 8 to 9 TU. The slightly higher value for groundwater suggests the presence of some water from the 1960s to mid-1980s with tritium concentrations higher than are measured in precipitation. In addition, the concentrations of tritium in groundwater decrease with time because the isotope is radioactive (half-life of 12.32 years; Lucas and Unterweger, 2000). Because of radioactive decay, the average tritium concentration of any groundwater sample derived from precipitation recharged since about 1982 in the Kabul Basin would be about 8 TU if measured today; however, because of the release of tritium to the atmosphere from atmospheric testing of nuclear weapons peaked in 1963, groundwater recharged between 1963 and 1964 would contain several hundred TU today, if not diluted or otherwise mixed. The ranges of tritium concentrations measured are 0.4 to 20.1 TU for groundwater, 11 to 18 TU for water from springs, and 6.5 to 11.2 TU for surface water. If the water samples are from the mid-1960s, then they have been diluted by mixing with older, low-tritium water. An alternate explanation is that the water samples might contain relatively high fractions of younger post-1970s water and thus lower concentrations of tritium.

Overall, it appears that most of the groundwater samples from the Kabul Basin are relatively young, as they contain CFCs and tritium, or are mixtures that contain a young fraction. Most appear to have infiltrated from streams and rivers within the past 30 years, but they have been affected by mixing processes. Groundwater age increases with depth below the water table (fig. 25); however, the results for one sample (from the Eastern Front Source Area) did not follow the general depth and age trend. This sample was from a deep well at the eastern area of the Deh Sabz subbasin where there is likely to be relatively little direct recharge and no recharge from irrigation leakage. The anomalously young age of this sample indicates a source of rapid recharge from groundwater inflow from the adjacent Kohe Safi Mountains.

The observed depth-age gradients suggest infiltration rates, adjusted for an assumed porosity of 25 percent, of 0.35 to 0.7 m/yr. Using an assumed porosity of 30 percent, a recharge rate of 0.4 to 0.8 m/yr was estimated. These rates are considerably higher than estimated basinwide recharge rates because the samples were collected primarily from irrigated areas where infiltration of surface water may locally contribute a large portion of the total recharge, and probably are not representative of the basinwide recharge rate.

Groundwater ages in the Kabul Basin

1. All of the water samples analyzed (from groundwater, springs, and surface water) contained CFCs and tritium, and therefore at least a fraction of the sampled water had been recharged since the 1950s.
2. Of the 41 groundwater samples (from 35 wells and 6 springs) analyzed for CFCs, the median apparent age was 21 years based on volume fractions of CFC-12 and CFC-11
3. The oldest water, with an apparent CFC age of 28–36 years, was from well 5
4. Tritium concentrations ranged from 4 to 21 TU in groundwater, 11 to 18 TU for water from springs, and 5 to 12 TU for surface water, and indicate that the groundwater samples likely contain relatively high fractions of post-1970s water.
5. Today the CFC concentrations in local surface waters are in near equilibrium with the modern atmosphere, but in the past there may have been local inputs of CFC-12 and CFC-11 that resulted in enrichment with respect to CFC-12, and to a lesser extent, CFC-11, as was measured in some of the groundwater samples.
6. The results suggest that little modern water was sampled. Most of the samples either predate the turnover in CFC air curves in the early 1990s or are dilutions of young water.
7. Seventeen groundwater samples were interpreted as mixtures of young and old water on the basis of CFC-113 and CFC-12 and found to contain relatively high fractions of young water with ages of 16 to 21 years. The fraction of young water in mixtures decreases with depth below the water table.
8. The average piston-flow ages based on CFC-12 concentrations range from 20 years (Paghman and Upper Kabul subbasin) to 28 years (Deh Sabz and Central Kabul subbasin), and from 15 to 19 years (Shomali subbasin) to 26 years (Central Kabul subbasin) based on CFC-113 concentrations (table 7). The ratio-based ages are slightly younger than the piston-flow ages (table 7).
9. Age gradients imply a vertical component of recharge of 0.35 to 0.7 m/yr, for an assumed porosity of 25 percent, infiltration of water beneath streams and rivers.

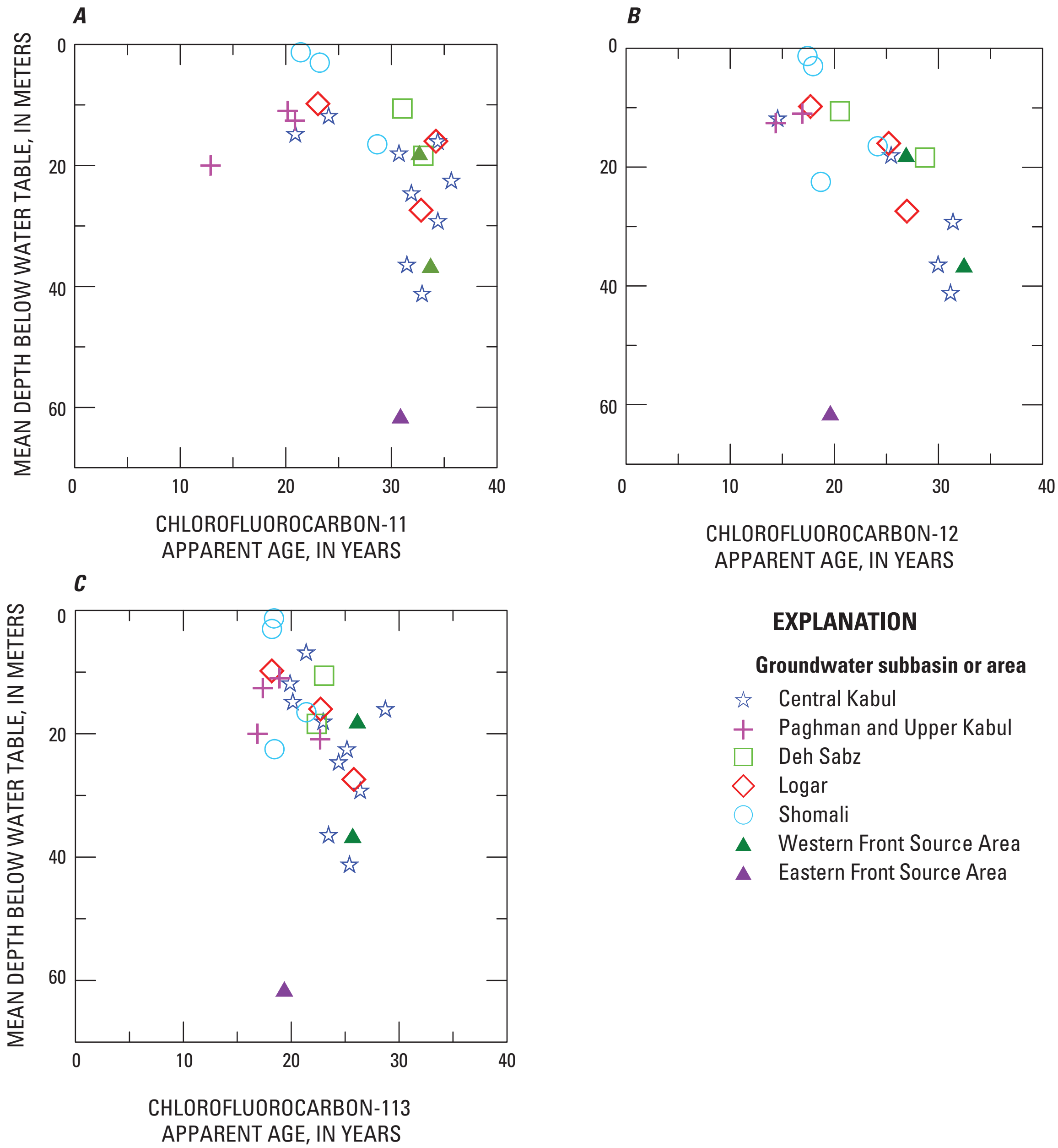


Figure 25. Apparent (piston-flow) ages as a function of depth below the water table. Symbols are at the midpoint of the saturated interval intercepted by the well. The ages were based on (A) CFC-11, (B) CFC-12, and (C) CFC-113.

Table 7. Summary of average ages, percentages of young water, and percentages of modern water, based on concentrations of chlorofluorocarbons and tritium in groundwater and water from springs by subbasin and source area in the Kabul Basin, Afghanistan.

[Location of basins shown on figure 6. CFC, chlorofluorocarbon; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, trichlorotrifluoroethane; TU, Tritium Unit]

Groundwater subbasin or area	Average piston flow ages in years[1]			Average ratio-based ages and percent young water [1]				Average percent modern[2]			Tritium in TU
	CFC-11	CFC-12	CFC-113	Age from CFC-113/ CFC-12 ratio	Percent young water from CFC-113	Age from CFC-113/ CFC-11 ratio	Percent young water from CFC-113	CFC-11	CFC-12	CFC-113	
Eastern Front Source Area	30	21	20	20	95	11	84	55	81	67	6.1
Western Front Source Area	28	23	21	23	77	17	71	85	86	68	12.0
Shomali	23	21	19	15	87	14	81	86	88	81	13.5
Deh Sabz	33	28	24	20	61	16	80	38	52	40	7.6
Central Kabul	34	28	26	17	66	18	65	63	394	39	8.4
Paghman and Upper Kabul	22	20	20	21	55	14	77	89	162	72	12.1
Logar	27	21	21	22	92	14	75	65	79	67	10.4

[1] Averages of all samples that could be dated using CFCs, excluding CFC contaminated samples.

[2] Average of all samples that could be dated using CFCs, including CFC contaminated samples.

Water Use

There is little to no direct data available for quantification of water use in the Kabul Basin. Water use in the Kabul Basin can be grouped into two main categories, domestic and agricultural. Total annual agricultural water use in the Kabul Basin is likely to be an order of magnitude greater than total annual domestic water use.

Municipal and Domestic

Total current domestic water use was estimated from the estimated population and an assumed annual average per person water-use rate of 30 L/d (11 m^3/yr) in rural areas and 40 L/d (15 m^3/yr) in the city of Kabul (table 3). Subkilometer-scale population estimates developed by the Oak Ridge National Laboratory's LandScan (2007) project for 2004 (Bhaduri and others, 2002; Dobson and others, 2000) were used to distribute population and water-use estimates spatially in the Kabul Basin. The LandScan population estimates were based on available census counts and modeled relations between population and land cover, roads, and nighttime lights. Estimated population counts by GIS 1-km grid cell (fig. 26) ranged from 0 to 10 in rural areas to about 62,000 in urban areas and were used to estimate total domestic water use at the kilometer scale. The current population patterns in the Kabul Basin (fig. 26) reflect locations where water is more readily available from karezes, streamflow diversions, or shallow groundwater. Presently there are no wastewater systems in the Kabul Basin, water used is returned on site or in nearby drainage ditches.

The future population is estimated to increase at a rate of 4 percent per year through 2012 (Mr. Rashid Fakhri, Central Statistics Office, written commun., 2007). This high rate of population growth is likely caused in part by many refugees returning to the Kabul area. The population of Kabul is expected to continue to grow, but estimates of population beyond 2012 were not available from provincial or national planners. The United Nations Population Division estimates a national population-growth rate of less than 1 percent per year and a total population for Afghanistan of 97 million by 2050 (United Nations Population Division, accessed July 16, 2008, at http://unstats.un.org/pop/dVariables/DRetrieval.aspx). The population of Kabul is currently about 10 percent of the country's total population and may continue to grow at rates greater than the national rate; however, growth projections are uncertain, and the actual growth rate will likely be a value between the provincial and countrywide rate projections. If the population grows at current rates (4 percent per year) for the next 5 years and 2 percent per year thereafter, the population in the study area may more than double from 3.3 million in 2007 to about 9 million by the year 2057.

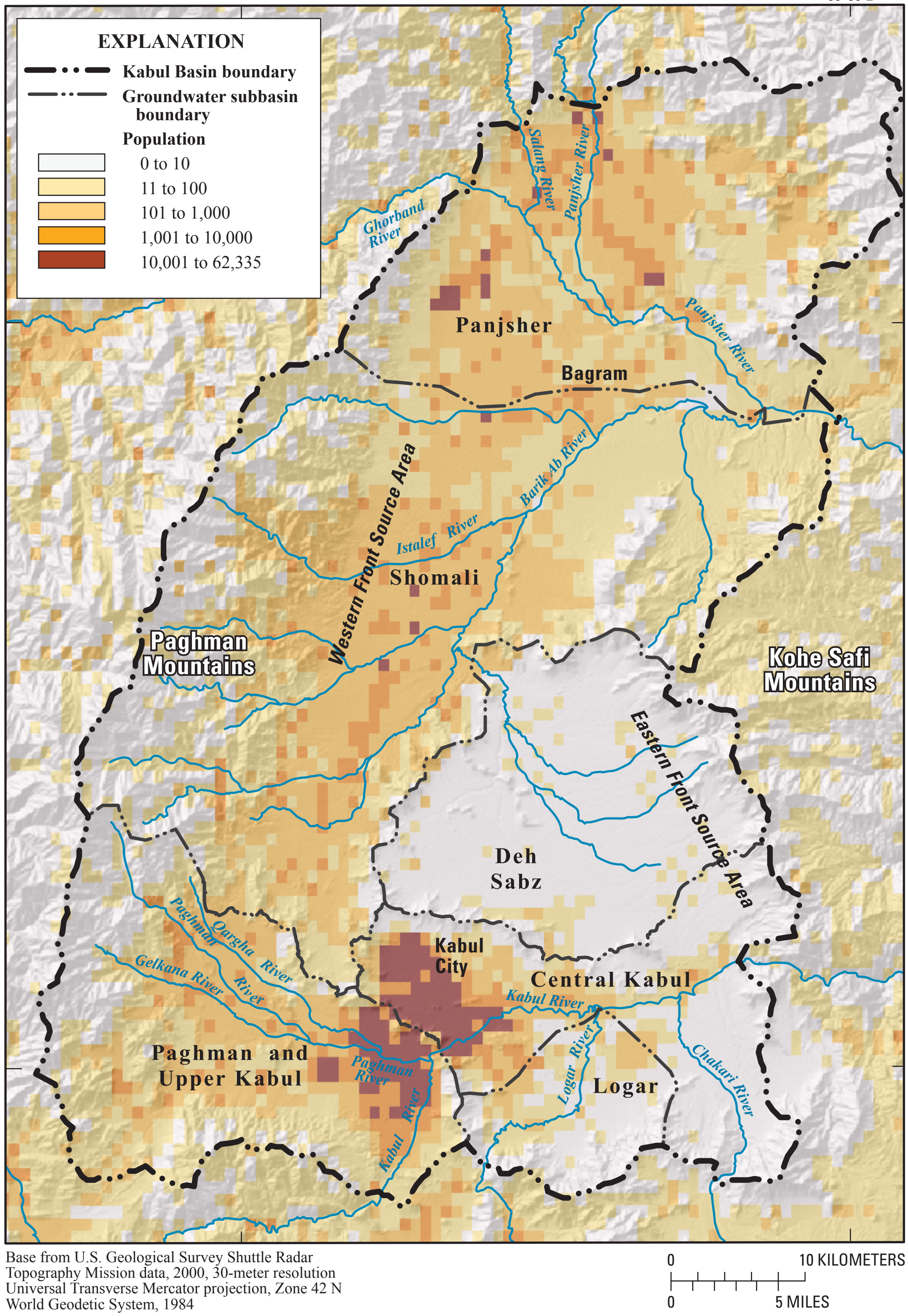


Figure 26. Estimated 2005 population in the Kabul Basin, Afghanistan (modified from Oak Ridge National Laboratory, 2007).

The per capita domestic water use may increase at a greater rate than the population because of increases in the standard of living and infrastructure. For example, the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) estimates that the per capita water-use rates of many other Central and West Asian countries are at least twice that of Afghanistan (accessed September 5, 2008, at http://www.unescap.org/stat/data/syb2007/26-Water-use-syb2007.asp). The per capita water-use rate used by this study, 30 L/d (or 11 m^3/yr), is about half of that estimated for Afghanistan by the UNESCAP (20.3 m^3/yr). Therefore, the per capita use rate of other nearby countries may be even greater than twice Afghanistan's rate. Under the assumptions of this investigation, the per capita water-use rate was assumed to increase 2 percent per year to 78 m^3/yr by the year 2057. The water demand for the city of Kabul has been estimated to increase to 330,000 m^3/d by the year 2025 (Lashkaripour and Hussaini, 2008). Based on the assumed population and water-use increases, municipal and domestic water use in the Kabul Basin was estimated to increase from approximately 112,000 in 2007 to 725,000 m^3/d annually by 2057. Future water use, therefore, was assumed to be about six times the current use and was distributed in proportion to current population patterns (fig. 26).

Agricultural

Irrigation water use has not been measured in the Kabul Basin. Agricultural water in Afghanistan is almost entirely supplied by streamflow diversions to irrigation canals (Banks and Soldal, 2002). In the study area, some irrigation water is supplied by karezes, but very little is supplied by groundwater withdrawals because of the lack of wells. Although many wells have been installed in the Kabul Basin, the use of groundwater for irrigation is still likely to be low because of the prohibitive cost of fuel for pumps. The amount of water used by crops, the actual evapotranspiration (AET), has been estimated by Senay and others (2007) for three major agricultural regions in the Kabul Basin (fig. 7), and water use in those regions was estimated on an annual and seasonal basis from 2000 to 2005 (Senay and others, 2007). The growing season is usually between May and September, and the 2005 season appeared to be a median year for agricultural water use in the Kabul Basin. In 2005, the total water use during the growing season for the three agricultural regions was more than 1,300 mm per region.

Irrigation efficiency in Afghanistan has been estimated to be as low as 25 to 30 percent because of leaking canals, evaporation losses, and inefficient terracing (Banks and Soldal, 2002). For example, Böckh (1971) attributes a 38-percent decline in flow in a reach of the Logar River in October 1963 to streamflow infiltration though permeable loam sediments. Because this loss occurred after the growing season, when agricultural water use should have been low, it can be attributed primarily to infiltration. It has been estimated that annual streamflow losses compose 72 percent of total groundwater recharge (Proctor & Redfern, Int., 1972, reported by Houben and Tunnermeier, 2005). The amount of water diverted from streams for irrigation is probably much greater than the amount that is actually used by crops.

Conceptual Groundwater-Flow Simulation and Water Availability

The conceptual groundwater-flow model integrates data and results from components of this study and other investigations to describe the groundwater-flow system in the Kabul Basin and estimate water availability. Because of limited data, the simulation model was not considered fully calibrated; for this reason, the results can be considered to provide only a conceptual understanding of the groundwater-flow system and a general representation of probable groundwater-flow conditions. The model is not suitable for application on a local or site-specific scale. The model was evaluated against historical base flows and historical and current water levels to assess how reasonably it approximates general groundwater flow conditions. The components of the groundwater-flow model are shown in figure 8, and the numerical representation and simulation of the fluxes, and model limitations, are discussed in detail in Appendix 14.

Conceptual Model

Total base flows, river inflows, estimated upland drainage, and estimated direct recharge were compared to outflows at the Panjsher River at Shukhi and the Kabul River at Tang-i-Gharu from the northern and southern basins, respectively (table 8). The total inflow to the northern subbasins is about five times the magnitude of the total inflow to the southern subbasins. Most of the flows in table 8 likely represent groundwater that has moved through the aquifer system and discharged at the outlets to the basins.

Total monthly recharge has been estimated to be about 0.001 to 0.002 m/d, for February, March, and April, with no recharge assumed to occur from May through October as a result of greater ET (Houben and Tunnermeier, 2005). Recharge estimates in this study were based on the mean monthly water balance, precipitation and evapotranspiration trends, and simulated mean annual groundwater flow from the subbasins. The mean annual rate of direct recharge on subbasin surface areas, not including irrigation leakage, was estimated to be about 0.0007 m/d. A mean monthly recharge rate was estimated to range from zero from June through September, to about 0.0005 m/d in November and May, to a high of 0.002 m/d in April (table 8). Table 8 does not differentiate aquifer recharge caused by irrigation leakage from other components of recharge because this component of the water balance is in the base flows listed in the table.

Table 8. Monthly mean base flows and balance of water in the (A) northern and (B) southern subbasins of the Kabul Basin, Afghanistan.

[Streamgage locations shown on figure 4; m/d, meters per day; km², square kilometer; m³/d, cubic meter per day; –, not calculated or not applicable]

(A) Northern subbasin areas - Panjsher River and Shomali subbasins

Month	Recharge rate	Base flow at Gorband River	Base flow at Salang River	Base flow at Panjsher River at Gulbahar	Base flow at Shatul River	Total base flows	Upland drainage at Western Front[1]	Estimated recharge on subbasin surfaces[2]	Total Inflows	Outflow base flow at Panjsher River Shuki	Difference between flows in and recharge, and flow out[3]	Difference: Inflow as a percent of outflow	Loss estimated actual evapo-trans - piration
Drainage or surface area		4,032 (km²)	435 (km²)	3,538 (km²)	202 (km²)		321 (km²)	1,698 (km²)		10,857 (km²)			700 (km²)
	(m/d)	(m³/d)	(m³/d)	(m³/d)	(m³/d)	(m³/d)	(m³/d)	(m³/d)	(m³/d)	(m³/d)	(m³/d)	(percent)	(m³/d)
October	0	767,703	290,363	1,488,090	28,455	2,574,611	30,145		2,604,757	2,382,786	221,970	109	0
November	5.1E-04	877,824	258,792	1,240,996	20,274	2,397,886	16,516	849,000	3,263,402	2,508,174	755,228	130	0
December	1.0E-03	840,068	243,078	1,050,498	16,758	2,150,402	12,341	1,698,000	3,860,743	2,783,094	1,077,649	139	0
January	1.0E-03	748,825	223,430	900,032	18,096	1,890,384	17,197	1,698,000	3,605,581	2,922,885	682,696	123	0
February	1.5E-03	744,322	256,248	886,425	27,922	1,914,917	33,375	2,547,000	4,495,292	2,631,050	1,864,242	171	0
March	1.5E-03	1,131,496	613,754	1,086,389	126,620	2,958,259	196,602	2,547,000	5,701,862	2,973,717	2,728,144	192	0
April	2.0E-03	2,509,114	1,654,895	2,302,261	503,230	6,969,499	814,661	3,396,000	11,180,160	6,605,295	4,574,864	169	0
May	5.1E-04	4,185,710	2,151,822	5,516,150	780,390	12,634,072	1,272,763	849,000	14,755,835	12,479,446	2,276,389	118	1,929,503
June	0	4,924,349	2,209,309	12,573,996	1,097,143	20,804,796	1,825,734	–	22,630,531	18,266,334	4,364,197	124	2,374,715
July	0	2,771,753	1,227,033	10,997,789	624,653	15,621,228	1,065,607	–	16,686,835	13,032,252	3,654,582	128	2,543,911
August	0	1,078,638	564,093	4,531,912	194,767	6,369,410	323,708	–	6,693,118	4,613,074	2,080,044	145	2,311,418
September	0	725,424	353,322	2,112,545	47,229	3,238,521	67,318	–	3,305,838	2,606,662	699,176	127	1,825,513
Annual mean	6.7E-04	1,775,435	837,178	3,723,924	290,461	6,626,999	468,686	1,940,571	8,231,996	6,150,398	2,081,599	134	915,422
median	–	–	–	–	–	–	–	–	5,098,577	2,948,301	–	–	–

Table 8. Monthly mean base flows and balance of water in the (A) northern and (B) southern subbasins of the Kabul Basin, Afghanistan.—Continued

[Streamgage locations shown on figure 4; m/d, meters per day; km^2, square kilometer; m^3/d, cubic meter per day; –, not calculated or not applicable]

(B) Southern subbasin areas - Paghman, Kabul, and Logar River subbasins													
		Base flow at Paghman River	Base flow at Kabul River at Tangi Saidan	Base flow at Logar River	Base flow at Chakari River	Total base flows		Estimated recharge on subbasin surfaces[2]	Total inflows	Outflow base flow at Kabul River at Tangi Gharu	Difference between flows in and recharge, and flows out[3]		Loss estimated actual Eeapo-trans-piration
Drainage or surface area		424 (km^2)	1,663 (km^2)	11,461 (km^2)	302 (km^2)			780 (km^2)		14,556 (km^2)		Inflow as a percent of outflow	110 (km^2)
Month	Recharge rate (m/d)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)		(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)	(percent)	(m^3/d)
October	0	6,948	30,837	197,697	26,724	262,207	–		262,207	159,020	103,187	165	0
November	5.0E-04	16,682	77,070	607,755	28,126	729,633	–	390,000	1,119,633	598,598	521,035	187	0
December	1.0E-03	31,062	125,501	993,429	12,042	1,162,035	–	780,000	1,942,035	1,113,143	828,893	174	0
January	1.0E-03	37,806	203,671	1,265,263	3,629	1,510,369	–	780,000	2,290,369	1,505,014	785,355	152	0
February	1.5E-03	39,368	223,111	1,351,579	7,853	1,621,911	–	1,170,000	2,791,911	1,716,568	1,075,343	163	0
March	1.5E-03	89,940	448,219	1,398,709	14,682	1,951,550	–	1,170,000	3,121,550	2,004,793	1,116,757	156	0
April	2.0E-03	230,948	1,206,439	1,511,726	36,649	2,985,763	–	1,560,000	4,545,763	3,028,203	1,517,560	150	0
May	5.0E-04	106,731	851,258	711,711	47,015	1,716,715	–	390,000	2,106,715	2,124,058	-17,344	99	101,554
June	0	13,362	360,894	117,465	43,468	535,190	–	–	535,190	475,357	59,832	113	140,397
July	0	8,685	69,564	64,252	32,168	174,668	–	–	174,668	130,624	44,044	134	141,450
August	0	6,369	25,817	29,655	28,766	90,607	–	–	90,607	39,755	50,852	228	129,868
September	0	6,382	24,455	35,750	27,807	94,394	–	–	94,394	41,080	53,313	230	105,298
Annual mean	6.7E-04	49,524	303,903	690,416	25,744	1,069,587	–	891,429	1,589,587	1,078,018	511,569	147	51,547
Median	–	–	–	–	–	–	–	–	1,530,834	855,870	–	–	–
							Rivers and uplands	Recharge	Total inflows	Outflows	Difference		ET Loss
Total annual mean flows							8,165,271	2,832,000	9,821,583	7,228,415	2,593,168		966,969

[1] Western Front shown on figure 1. Upland drainage calculated based on a monthly base flow per unit area for the Shatul River drainage.

[2] Assuming recharge varies from October to September as indicated in table column 2.

[3] Because of changes in storage, unknown components in the water balance, and because inflow and outflows were mean values, inflows do not necessarily equal outflows.

During the nongrowing season, October through March, aquifers in the subbasins gain water. From November through February, aquifers in the northern subbasins gain water at a rate of about 10 to 30 percent of the inflows, whereas aquifers in the southern basins gain water at a rate of about 40 percent of inflows. This water is stored in the aquifer, and it is used or discharged later in the year. From March through April, inflows are 50 to nearly 100 percent more than outflows, and the aquifer systems gain water at higher rates. During the growing season (May through September), the sum of agricultural water use (AET) and ET (in nonagricultural areas) may be equal to or greater than the difference between inflows and outflows. During September, AET water use is greater than the difference between inflows and outflows and may also be augmented by groundwater discharges to streams and karezes. Unaccounted inflows to the aquifer system are likely to occur early in the growing season as some portion of high flows (fig. 14), which are not represented by the base flows shown in table 8, are applied to irrigated areas and result in additional leakage to the aquifers. In the northern subbasins, the monthly AET water use is generally similar in magnitude to the balance of available inflows (inflows minus outflows). The monthly AET is greater than the balance of available inflows in the southern basins because of the smaller inflows and is therefore a larger component of the overall water balance than in the northern basins. Leakage in irrigated areas may also account for the monthly water-balance differences and was estimated at an annual rate to be about 0.0012 m/d. Isotopic analysis of groundwater sampled from different depths in the Kabul Basin supports a total annual recharge rate equal to direct recharge plus irrigation leakage of about 0.002 m/d.

Steady-state groundwater-flow in the aquifer system was simulated on the basis of mean annual inflows and outflows from the system (table 8). Simulated groundwater heads for the uppermost model layer, shown in figure 27A, represent the water table in the surficial aquifer, which is composed of unconsolidated Quaternary and recent sediments. Figure 27B shows simulated heads in the Neogene aquifer in the lower altitude areas and bedrock in the upland areas. The simulated groundwater heads, which were generally within 10 m of the observed groundwater levels in the lower altitude areas near the centers of the subbasins, matched regional water-level patterns well (appendix 14). Larger errors were apparent near the valley walls where some simulated levels were much lower than the observed levels. Groundwater-flow conditions are often difficult to represent accurately near valley walls or other areas with contrasts in hydrologic environments. Although heads simulated by the conceptual model may not be accurate at a local scale, the model can be used to calculate regional heads in the groundwater-flow system and the effects of changes on the system.

Recharge in the Kabul Basin varies spatially and was simulated with a mean annual rate of 0.0007 m/d for direct recharge plus an additional 0.0012 m/d in agricultural areas (table 8). Some areas of the Kabul Basin, such as the Deh Sabz or eastern Shomali subbasins, have much less water available than areas near the major rivers. For example, the western Central Kabul subbasin, the central and western Deh Sabz subbasin, and the eastern Shomali subbasin are likely to recieve very little recharge. The widely spaced water-table contours in these areas in figure 27A indicate that groundwater-head horizontal gradients are relatively low. Areas of groundwater discharge to the major rivers are also indicated by the curvature of the simulated contours (fig. 27A). In the eastern parts of the Paghman and Upper Kabul and eastern Central Kabul subbasins, groundwater discharges to the Kabul River. In the eastern parts of the Shomali and Panjsher subbasins, groundwater discharges to the Panjsher River.

In some areas near the Western and Eastern Front Source Areas, groundwater levels, perennial flow through karezes, and groundwater-sample analyses indicated that there were additional sources of groundwater inflow to the basins. Simulated groundwater levels at the Eastern Front Source Area in the Deh Sabz subbasin were low in areas where groundwater heads have been measured 20 to 40 m below land surface, and karezes are known to flow perennially. There is essentially no upland drainage from the Kohe Safi Mountains into the Deh Sabz subbasin because the surface-water drainage divide is close to the valley wall, and all surface water from this mountain range flows east to the Panjsher River outside of the Kabul Basin. Groundwater, however, flows into the eastern Deh Sabz subbasin from the Kohe Safi Mountains and was simulated in the model (fig. 8). The altitudes of the land surface at the Eastern Front Source Area, the center of the Deh Sabz subbasin, and the ridge at the edge of the valley are generally about 1,900, 1,800, and 2,500 m, respectively. Although surface drainage east of the ridge is away from the Kabul Basin, the area east of the ridgeline is higher than the Deh Sabz subbasin, and some groundwater likely flows through the sedimentary rock of the Kohe Safi Mountains to the Eastern Front. Along the Eastern Front, groundwater may flow from the Deh Sabz subbasin toward the Central Kabul subbasin (fig. 27A). Groundwater likely flows through the gaps in the ridgeline between the Deh Sabz and Central Kabul subbasins into the central area of the Deh Sabz subbasin (fig. 27A). The gaps between the ridges that separate these subbasins, where groundwater can readily flow through unconsolidated sediments, however, are narrow (about 1,000 m wide). Groundwater flow into the Deh Sabz subbasin from the Central Kabul subbasin is a small fraction of total recharge to Deh Sabz. The source of recharge in this basin is primarily infiltration of winter precipitation. Chemical analyses of groundwater samples from this area indicate little evaporative concentration, probably because depths to water are greater than in other subbasins, and vegetation is relatively sparse.

Simulated groundwater levels (fig. 27A) illustrate the effects of recharge to the surficial aquifer from leakage from perennial streams that drain into the valley from the Paghman Mountains. Chemical analyses indicate that additional sources of recharge are also likely at the Western Front Source Area adjacent to the Paghman Mountains (figs. 1 and 8). The Paghman Mountains are composed of metamorphic rocks which generally have relatively low groundwater storage and transmissivity. Because there are a number of faults along the western front of the Paghman Mountains (fig. 3), the bedrock is likely to be more highly fractured and to have higher groundwater storage and transmissivity than metamorphic rocks elsewhere in the Kabul Basin. The faulted zone at the base of the Paghman Mountains may enhance groundwater inflows to the surficial and Neogene aquifers at the Western Front as indicated by the simulated head surface in the Neogene aquifer (fig. 27B).

Estimated Water Availability

Estimating the water availability in the Kabul Basin requires estimating the balance of flow in the system. A general water balance consisting of monthly mean base flows in and out of the rivers in the Kabul Basin was calculated for the northern and southern subbasin areas (table 8). On an annual basis, base flows into the Kabul Basin are about equal to or slightly greater than base flows out of the basin. The difference may be a result of agricultural water use and ET. In the southern basins, with less agricultural use and possibly less ET, inflows were essentially balanced by outflows.

Inflow into the northern basins is from the rivers and tributaries that drain into the Panjsher River at Shukhi (fig. 13) and from precipitation to the Shomali, Deh Sabz, and Panjsher subbasins (figs. 1 and 8); inflow into the southern basins is from the rivers that drain to the Kabul River at Tang-i-Gharu and direct recharge onto the Paghman and Upper Kabul, Central Kabul, and Logar subbasins (figs. 1 and 8). Mean monthly base flows were calculated from historical streamflow-gaging data (fig. 13, appendix 8). Mean monthly base flows in perennial streams discharging from the Paghman Mountains to the Western Front Source Area (fig. 1) were calculated per unit area based on the Shatul River drainage area (fig. 13, table 2); the Shatul drainage-area baseflows represent median unit discharges for the smaller watersheds draining into the Kabul Basin. The area contributing to perennial streams draining the Paghman Mountains (321 km^2) at the Western Front (fig. 1) is slightly larger than the Shatul River drainage area (202 km^2). Upland-drainage discharge was not calculated for the Kohe Safi Mountains along the Eastern Front because of the limited upland area and lack of perennial streams.

Integrating information about the sources of recharge to the Kabul Basin with the estimates of the hydraulic properties of the aquifer and of the thickness of the unconsolidated sediments provides a conceptual representation of the potential water availability in the basin (fig. 28). Information about the components of the groundwater-flow system was incorporated into the availability analysis on the basis of the estimated contribution to the flow for each component including sediment thickness, aquifer geometry, and sediment and bedrock hydraulic properties calculated by the groundwater-flow model. This information was integrated with additional information provided by the isotopic and geochemical analysis of groundwater (appendixes 11 and 12) and model calibration (appendix 14). The components determined by this study to the be most important characteristics contributing to groundwater availability in the Kabul Basin were: sediment and bedrock hydraulic characteristics, faults and lineaments in bedrock areas, areas of streamflow leakage, irrigation leakage, groundwater inflow from the mountain fronts (represented by distance from the mountain fronts), and aquifer thickness. Components of the groundwater-flow system were assigned a relative rank of 0 for no contribution to 10 for a relatively high contribution to the flow system and were added together (by using the Weighted Sum routine in ArcMap). For example, to account for potential for sustained streamflow leakage, northern perennial streams with source areas outside the Kabul Basin, including the Panjsher River and its tributaries, were given a high rank (10); southern perennial streams with source areas outside the Kabul Basin, including the Kabul and Logar Rivers, were ranked 7; streams which originate in the Paghman Mountains were given a moderate rank (5); and ephemeral streams that drain areas with little to no upland area, such as those in the Deh Sabz subbasin, were given a rank of 0.

Simulated groundwater-head contours in the Neogene aquifer (fig. 27B) have been superimposed on the colored areas representing potential water availability to show the relation between the two parameters. More water is estimated to be available in northern areas of the Kabul Basin adjacent to the Panjsher River and its tributaries. Potential water availability is also relatively high along the Western Front Source Area as a result of stream leakage, groundwater inflows from the Paghman Mountains, and aquifer sediments that are estimated to be thick. Potential water availability in the Deh Sabz subbasin is generally low because there is essentially no stream or agricultural leakage in this area. Figure 28, however, indicates some groundwater inflow to the Deh Sabz subbasin from the Kohe Safi Mountains to the east. Potential water availability in the Central Kabul subbasin is also low, although aquifer sediments are more than 300 m thick, except where the Paghman, Kabul, or Logar Rivers and adjacent irrigated areas provide leakage to the underlying aquifer.

A **Model layer 1**

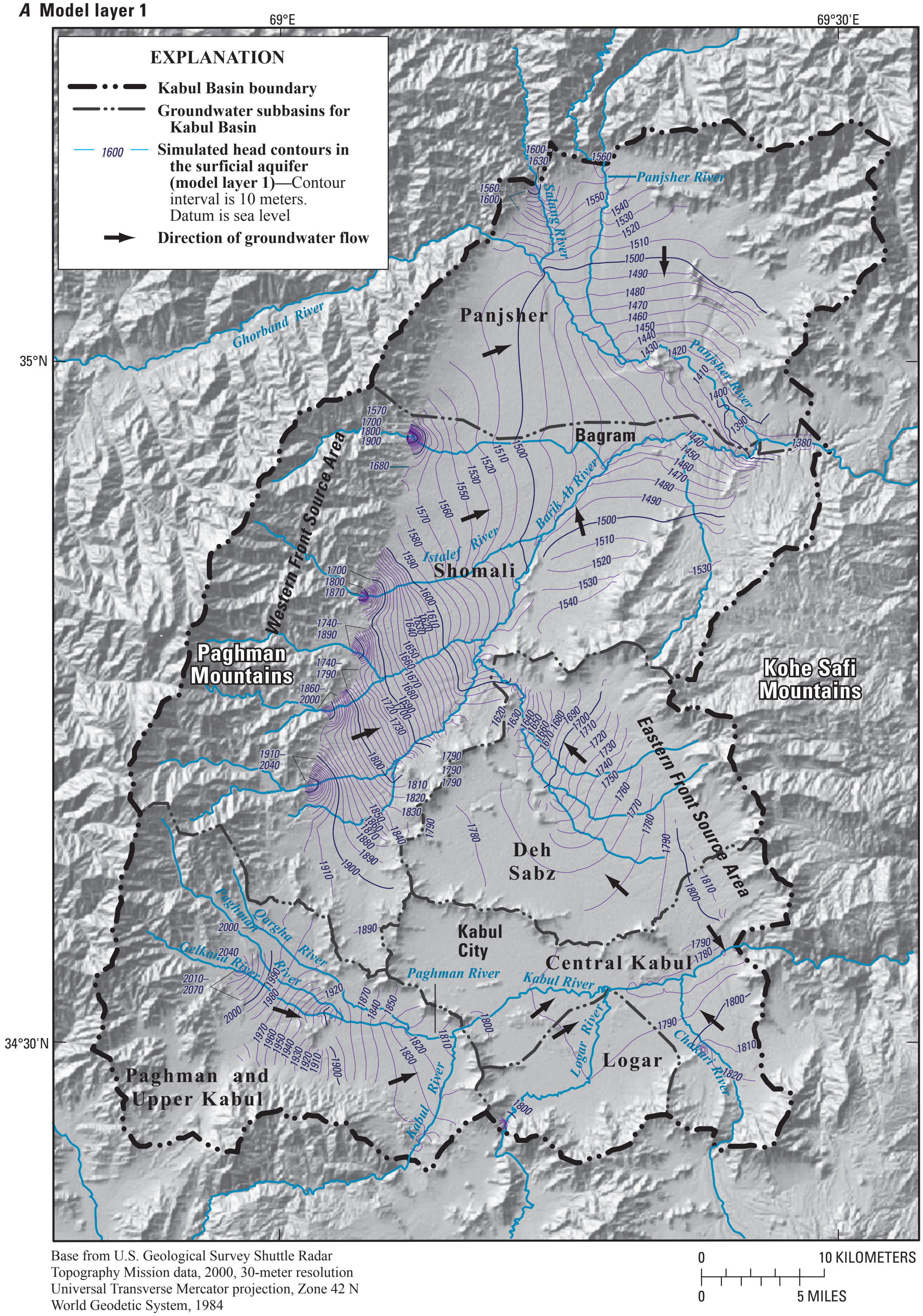
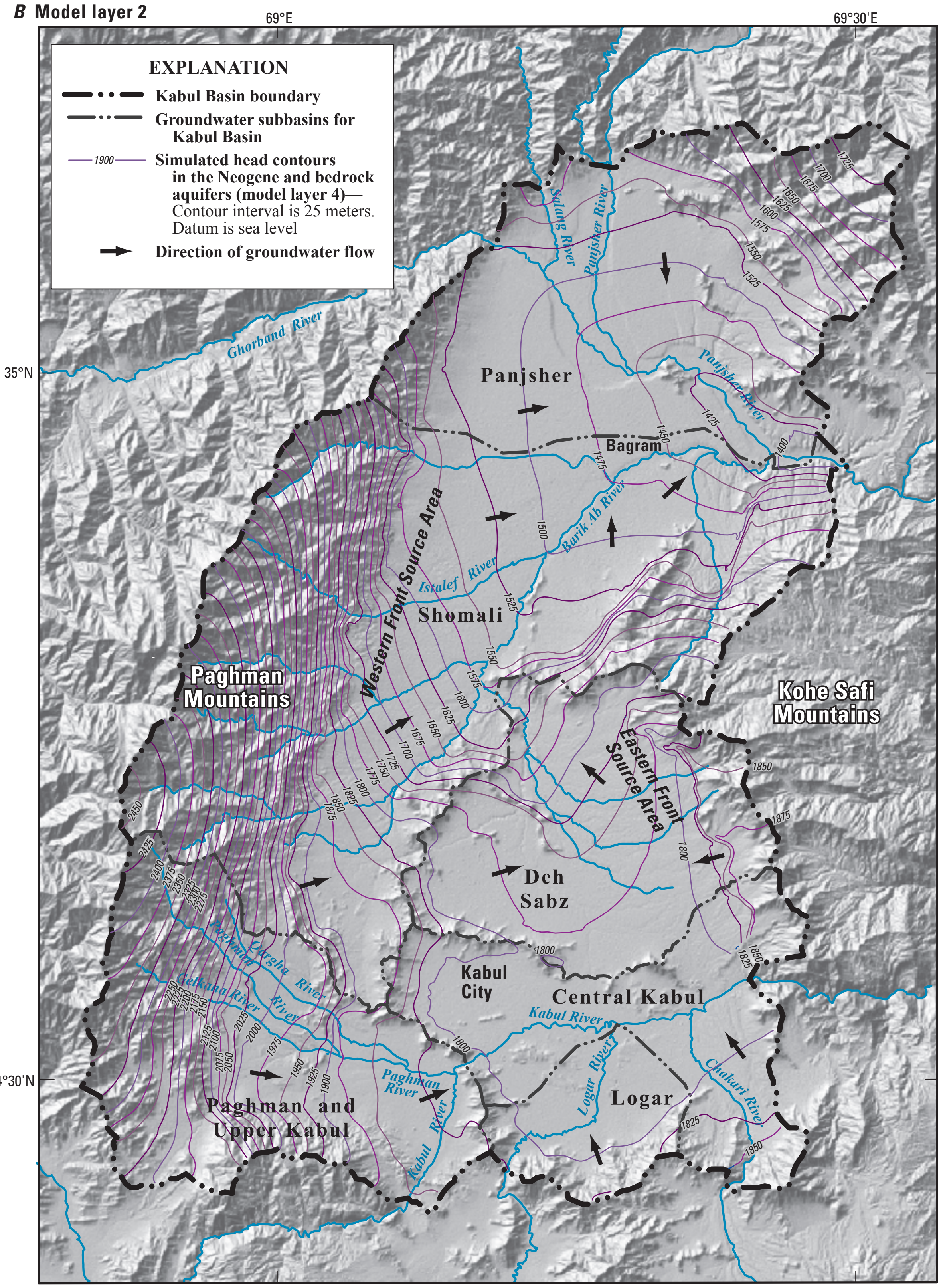


Figure 27. Simulated groundwater heads in (A) model layer 1, representing the water table in unconsolidated sediments in the subbasins, and (B) model layer 2, representing the head surface in the Neogene aquifer in the lower altitude areas and the bedrock aquifer in the upland areas of the Kabul Basin, 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 27. Continued.

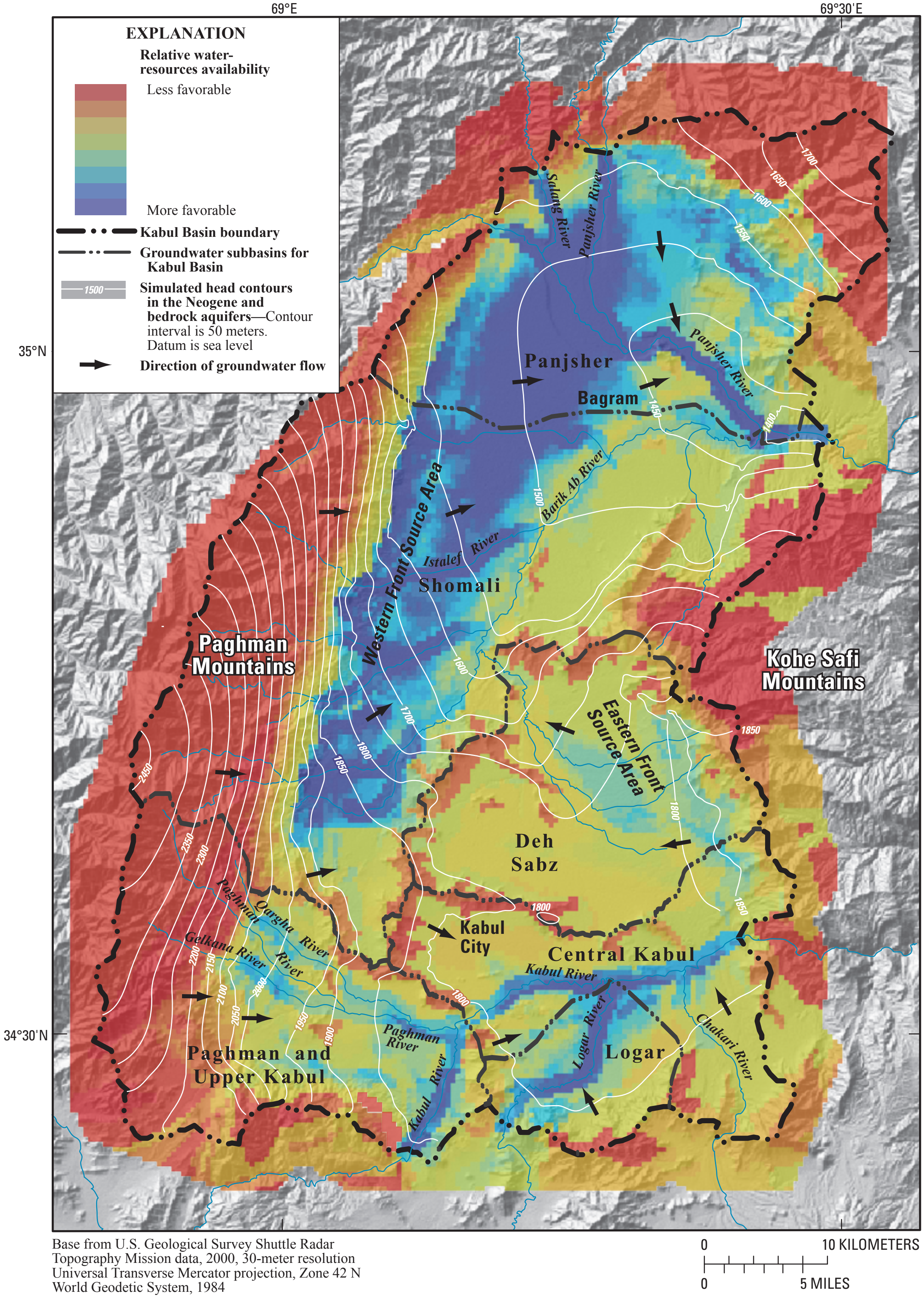


Figure 28. Water-resources availability based on an integration of estimated hydraulic properties, stream leakage, irrigation leakage, inflows from mountain fronts, and aquifer thickness in the Kabul Basin, Afghanistan.

Simulated Effects of Population Growth on Water Resources

The population in the Kabul Basin is expected to increase by 20 percent, from approximately 3.3 to 4 million, in the next 5 years. Population growth and increasing per capita water use were assumed to result in about a sixfold increase in total annual municipal and domestic water use by the year 2057. The effect of the increased 2057 population on water resources was simulated by increasing domestic and municipal withdrawals in the surficial aquifers by a factor of 6 and assuming a population distribution in the Kabul Basin similar to the recent (2005) population pattern (fig. 26). A steady-state simulation was used for future withdrawals to represent the regional long-term effects of increased withdrawals in the surficial aquifer. For purposes of this analysis and comparison of simulations, the extents of irrigated areas and the irrigation water-use rate were assumed to be the same as under current conditions. Although the amount of irrigated land area may increase or decrease in the future because of climate-related factors, the water-use rate for irrigation was held constant to isolate the effect of one variable—increasing domestic and municipal water needs—on regional water availability.

The groundwater-head contours in figure 29 show the simulated steady-state drawdown resulting from the hypothetical sixfold increase in groundwater use in the Kabul Basin. Groundwater levels in rural, less populated areas of the model were simulated to decline by about 1 m or less. In the more populated areas, declines were simulated to be more than 2 m (fig. 29). Large declines of 10 to about 40 m were simulated for the western areas of the Central Kabul subbasin (fig. 29). Presently, the water in most local supply wells is shallow, less than 10 m deep. This hypothetical scenario indicates that many such wells could possibly become dry under the simulated conditions.

Simulated groundwater-level declines were large in the western part of the Central Kabul subbasin near the interbasin ridges because this area receives very little recharge from direct precipitation, and the dense population creates the greatest water demand. The area receives some recharge from streamflow leakage; however, such leakage may not be adequate to supply the western area of Central Kabul subbasin.

The simulated groundwater declines caused by increased municipal and domestic use would be greatest in urbanized areas and would affect shallow supply wells more than deep wells. The mean depth of NGO-installed wells in the Kabul Basin is approximately 22 m, and the mean depth to water in such wells is about 12 m. Groundwater levels in the surficial aquifer typically fluctuate about 0.5 to 3 m annually in the more urban areas (Akbari and others, 2007; Safi and Vijselaar, 2007). Drawdowns of 5 to 25 m have been measured at pumped supply wells (Akbari and others, 2007). Therefore, the saturated lengths of casing or of aquifer thickness in tube wells or dug wells may typically be less than 10 m, and shallow supply wells may typically draw groundwater from only the top few meters of the aquifer. Of the more than 1,000 shallow supply wells in the Kabul Basin, more than half (54 percent) would undergo water-level declines of more than 0.5 m, and 36 percent would undergo declines of more than 1 m. Simulated groundwater-level declines caused by increased withdrawals, without the additional effect of prolonged droughts, may result in about 40 percent of existing shallow supply wells, primarily in urbanized areas, becoming seasonally inoperable or completely dry.

The withdrawals simulated in this manner may be greater than the actual withdrawals that could be obtained from the surficial aquifer at specific locations because of local geologic factors such as impermeable sediments or rock or a prohibitive depth to water. Additionally, future withdrawals are likely to be supplied by large groundwater-withdrawal operations at high-yielding areas of the aquifer system and not by the pattern of wells simulated in this analysis. This study also does not assess the placement of individual withdrawal wells but evaluates the potential hydrologic effects of increasing withdrawals from the regional aquifer.

Simulated Effects of Withdrawals from the Upper Neogene Aquifer

The potential effects of groundwater development in the Neogene aquifer were assessed by simulating additional withdrawals from hypothetical wells under steady-state conditions in the upper Neogene aquifer. The hypothetical wells were arbitrarily placed at population centers in six subbasins (at the centers of the drawdown areas shown in fig. 30), to illustrate the effects of withdrawals in different areas of the Kabul Basin and do not represent suggested or potential well locations. The simulated wells were pumped at a rate of 10,000 m^3/d from the top 100 m of the Neogene aquifer. The analysis used current (2007) estimated municipal and domestic and agricultural water-use rates from the surficial quaternary aquifer.

The effects of simulated withdrawals from the Neogene aquifer are illustrated by groundwater-level declines (fig. 30) relative to the current simulated head surface (fig. 27A) in the surficial aquifer. Simulated declines were limited by the thickness and low permeability of the upper Neogene aquifer; however, water levels in shallow supply wells would be affected in areas where declines are indicated. Simulated declines were generally less than 0.2 m in the Shomali and Panjsher subbasins. Simulated drawdowns were greater (0.4 m or more) in the smaller subbasins and in areas with less direct recharge, such as the Paghman and Upper Kabul, Central Kabul, and Deh Sabz subbasins. Nearly all shallow supply wells would be affected to some degree by the simulated withdrawals from the Neogene aquifer in these three subbasins. Simulated drawdowns in the Central Kabul and the Paghman and Upper Kabul subbasins affected a larger area than drawdowns elsewhere in the Kabul Basin because the extent of the Neogene aquifer is limited to the small area underlying these subbasins. Simulated drawdowns in the Deh Sabz subbasin affected a larger area because the recharge in this subbasin is lower than the recharge in the other subbasins.

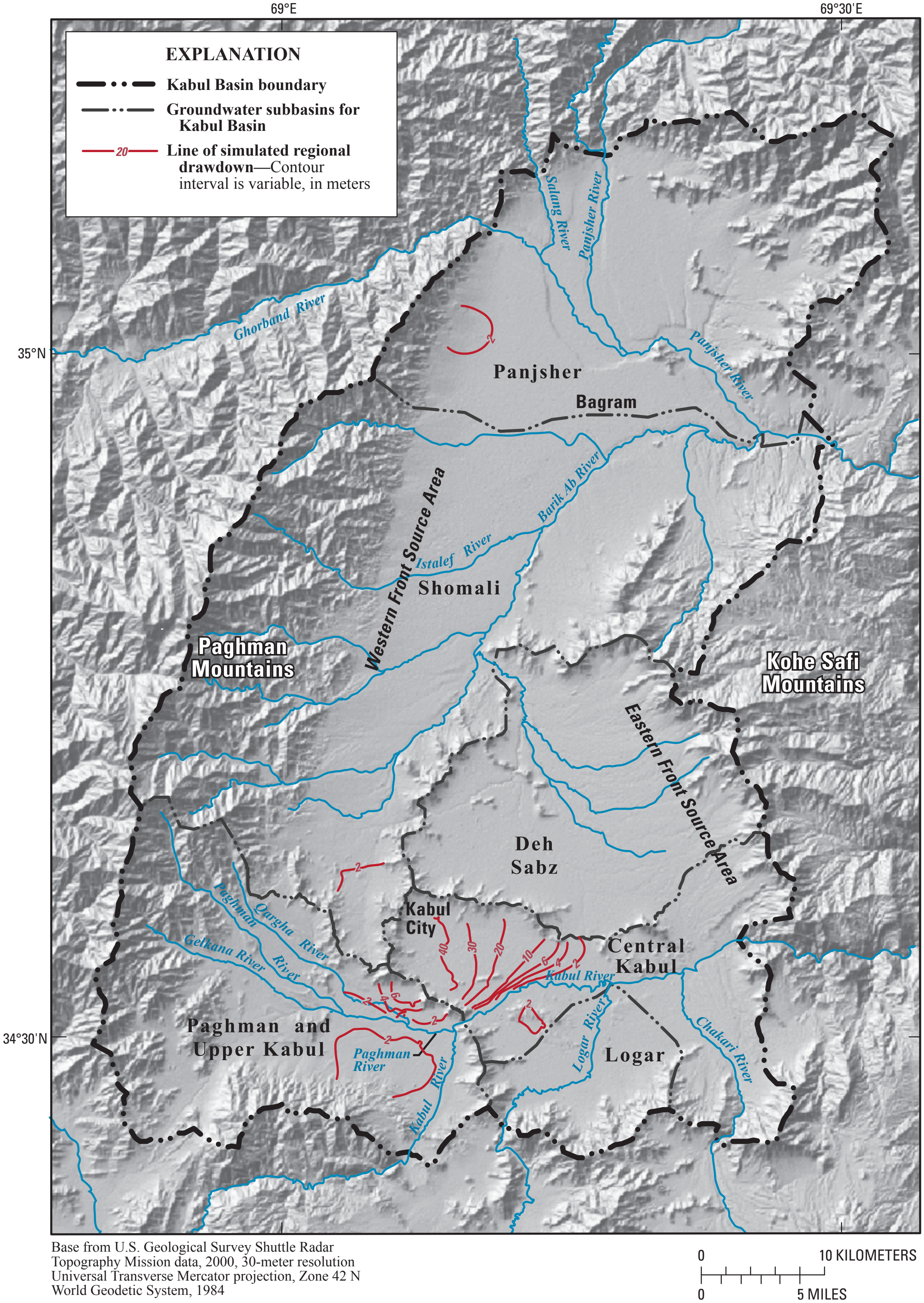
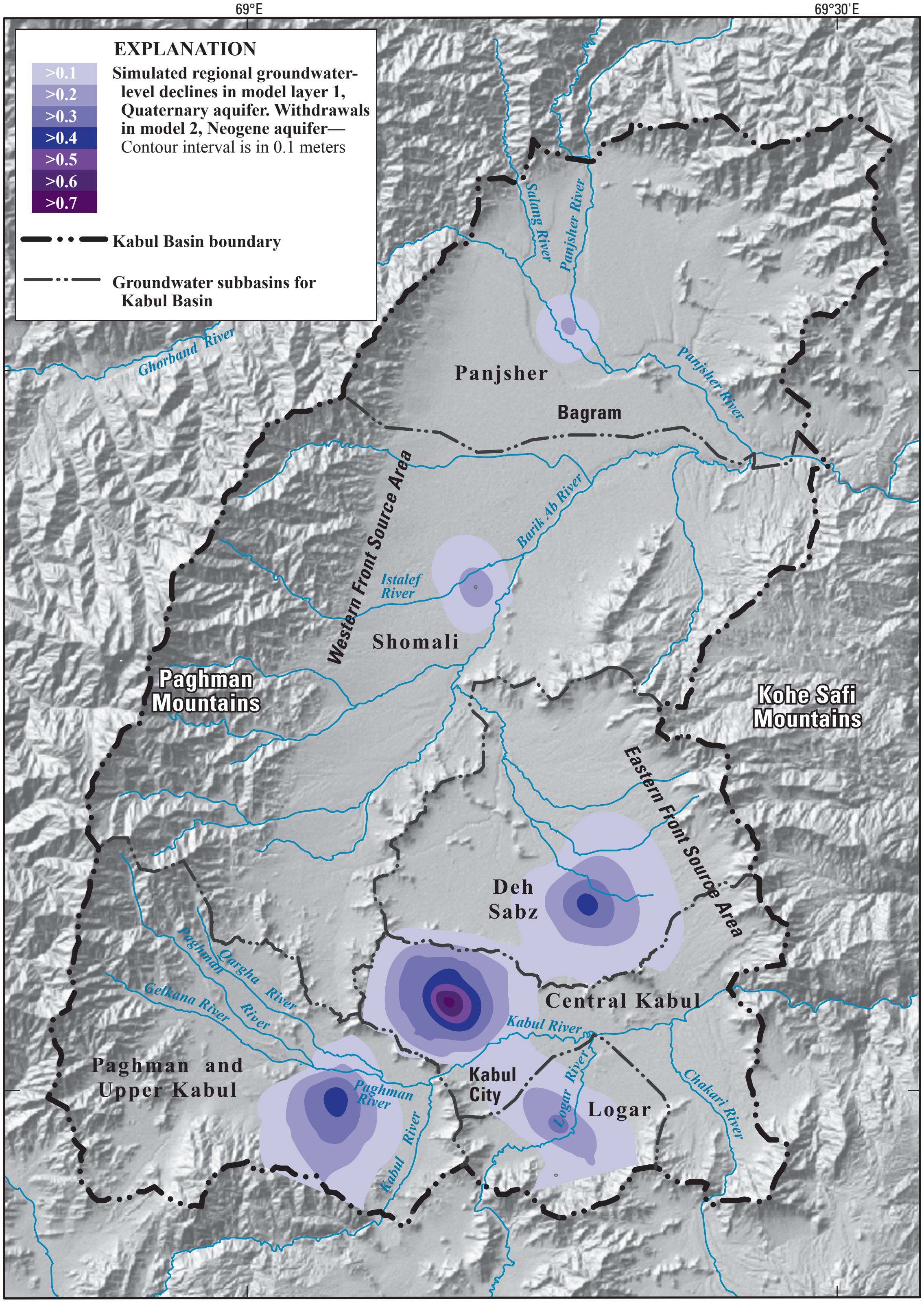


Figure 29. Simulated regional drawdown in the surficial aquifers caused by a hypothetical sixfold increase in water use in the Kabul Basin, Afghanistan.



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

0 10 KILOMETERS
0 5 MILES

Figure 30. Regional groundwater-level declines caused by withdrawals from the upper Neogene aquifer simulated by the conceptual model of the Kabul Basin, Afghanistan.

Potential sources of water to withdrawals in the upper Neogene aquifer within the regional groundwater-flow system were assessed in the Kabul Basin by particle-tracking methods (Pollock, 1994). In the Panjsher subbasin, the simulated groundwater flow in the upper Neogene aquifer is supplied by inflows from the large rivers entering the Kabul Basin. In the Shomali subbasin, the source of water to the upper Neogene aquifer is simulated as originating from leakage from perennial streams and groundwater inflows from upland areas. The source of water to withdrawals in the upper Neogene aquifer in the Paghman and Upper Kabul, Deh Sabz, and Logar subbasins was simulated as primarily originating from groundwater inflows from upland areas outside the subbasins. The simulated source of water to the Central Kabul subbasin was primarily direct recharge on the area west of the subbasin. Withdrawals in the upper Neogene may create a downward head gradient in the subbasin and induce flow from the river; however, simulations indicate that the water captured at a well in the upper Neogene aquifer may not necessarily be from a nearby river. The simulated groundwater-level declines in the Central Kabul subbasin illustrate a scenario in which withdrawals in the upper Neogene aquifer induce river infiltration.

The age of groundwater along simulated flowpaths can be calculated by using the groundwater-flow model; and a conceptual understanding of the relative age of groundwater in the upper Neogene aquifer, can be gained from the results of simulations. The results of the simulations are controlled by numerous variables such as hydraulic conductivities, porosity, and simulated fluxes; the values of these variables, however, are not well known, particularly for the Neogene aquifer. Recent (2008) chemical and isotopic analysis (including tritium and carbon 14 sampling of groundwater from two wells in the Bagram area by the AGS and USGS) provide new information (not included in Appendix 10) on the age of groundwater at the base of the surficial (Quaternary) aquifer or at the top of the Neogene aquifer. The interpreted residence times of groundwater samples from depths of 73 and 100 m were 300 and 2,800 years with modern fractions of 84 and 58 percent respectively (Neil Plummer, USGS, written commun., 2009). Given the results of recent sampling and the low recharge rates at the surface, the age, or residence time, of groundwater in the upper Neogene aquifer is most likely several orders of magnitude greater than the age of groundwater in the surficial aquifer. Additional isotopic-age analysis of groundwater from the Neogene aquifer would be necessary to provide confidence in the results of flowpath ages. The sustainability of groundwater in the Neogene aquifer in subbasin areas like the western part of the Central Kabul subbasin, which is bounded by interbasin ridges, may be much less than that of the groundwater in the Neogene aquifer in the northern and western areas of the Kabul Basin, which are bounded by large mountains. Recharged by river leakage and mountain-front recharge in the northern Kabul Basin, groundwater flowing into the upper Neogene aquifer in the western areas of the Shomali and Panjsher subbasins and in the eastern area of the Deh Sabz subbasin is likely to be younger than groundwater in the upper Neogene aquifer in central subbasin areas bounded by interbasin ridges. For example, groundwater in the more populated western area of the Central Kabul and the eastern area of the Paghman and Upper Kabul subbasins is likely to be much older, possibly tens of thousands of years older, than groundwater in the other subbasins; the water is older because it has flowed farther from the source of recharge.

Simulated Effects of Climate Change

Potential changes in groundwater conditions caused by climate change were simulated for a 2057 scenario. Potential climate change may affect both the total annual recharge to the Kabul hydrologic system and also the timing of recharge during the year. Although water demand for the year 2057 is projected to be higher than current demand, the simulated climate change was evaluated on the basis of current water-use conditions to allow assessment of the impact of climate change alone, as a single variable, without other complicating factors. Projected climate conditions simulated in this investigation included changes in precipitation amounts and patterns, ET rates, and growing-season length (fig. 10), all of which could result from rising temperatures (fig. 9). The effects of such climate changes on regional precipitation rates were based on the research of Milly and others (2005) for southeast Asia and similar watershed simulations for the Helmand Basin of Afghanistan (Vining and Vecchia, 2007). By the year 2057, total monthly precipitation is estimated to decline by about 10 percent; however, the timing of peak runoff, and therefore peak recharge in the Kabul Basin, is expected to occur earlier in the year with increasing temperatures (fig. 9), as is indicated in figure 16. The earlier inflows from earlier peak runoff may shift a portion of the peak recharge from April into March.

The potential effect of climate change on water availability in the Kabul Basin aquifer system was assessed by simulating a 10-percent reduction in precipitation. The steady-state analysis was based on current estimated water-use rates, and the results were compared to simulated current groundwater conditions (fig. 27A). A regional reduction in precipitation would also affect the external drainage basins and adjacent upland areas that contribute inflows to the Kabul Basin. Climate change was simulated by reducing the following inflows to the model by 10 percent: (1) direct recharge from precipitation, (2) inflows from perennial streams draining upland areas, (3) inflows from rivers entering the Kabul Basin, and (4) irrigation recharge, which is likewise dependent on the surface-water inflows.

A 10-percent reduction in recharge results in a decline in groundwater levels throughout the Kabul Basin (fig. 31). Declines of more than 0.5 m were simulated for most of the model area. Declines of more than 10 m, and in places more than 20 m, were simulated for the Western Front Source Area and in the upper areas of the Paghman and Upper

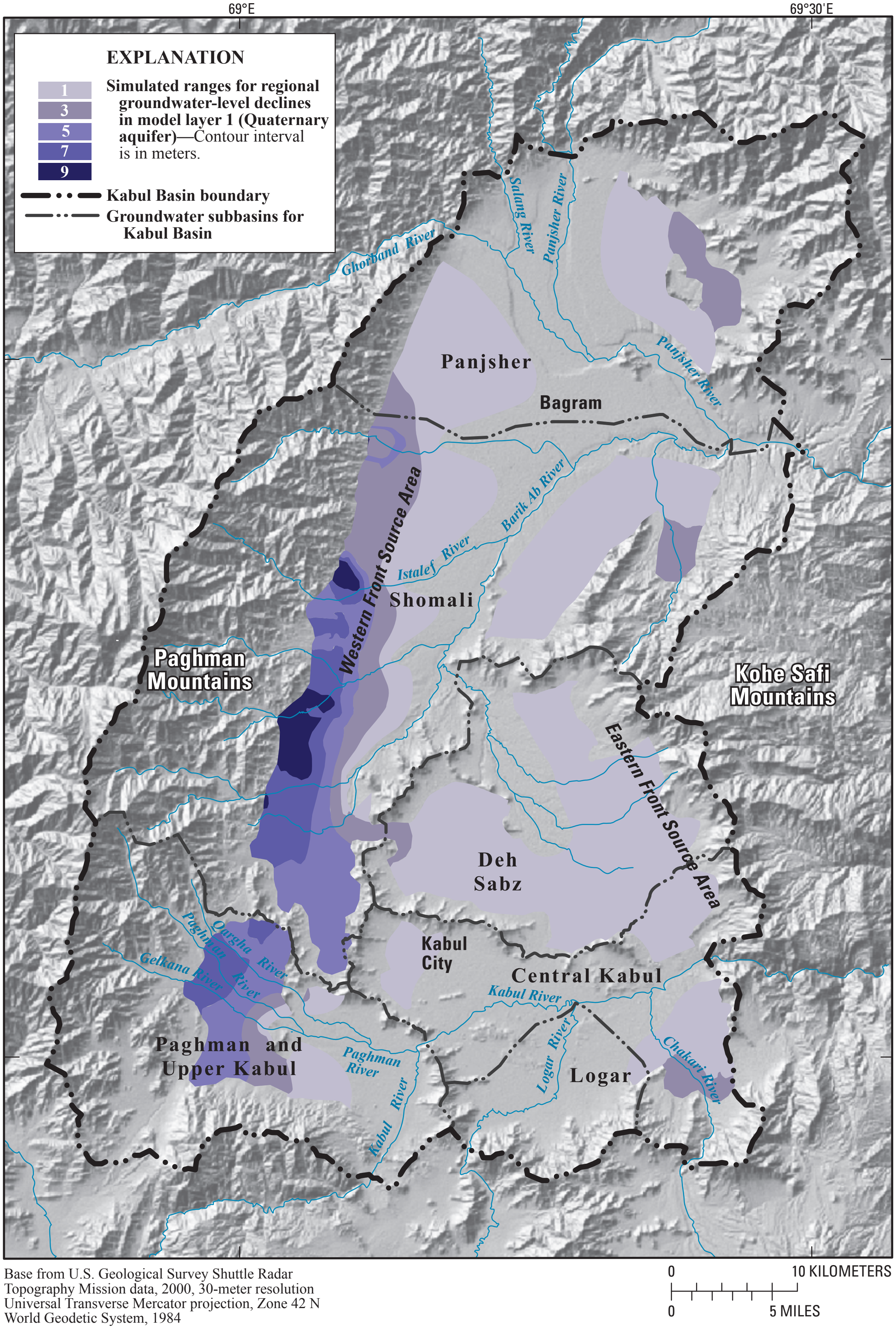


Figure 31. Simulated regional groundwater-level declines in subbasin surficial aquifers following a reduction in recharge caused by potential climate change in the Kabul Basin, Afghanistan.

Kabul subbasin; these declines were caused by reductions in inflows from perennial streams and upland drainages from the Paghman Mountains. Large groundwater-level declines (more than 10 m) at the Western Front Source Area would reduce stream and karez flows into the valley. The simulation results (fig. 31) indicated that mean annual changes in the hydrologic system and more pronounced changes in the flow system would occur seasonally, particularly during low-flow periods. Although not simulated, the reduced precipitation would also affect the timing of peak snowmelt and therefore peak recharge. Peak recharge earlier in the spring or late winter would result in less groundwater discharge (from storage) to streams and karezes during summer dry periods.

Simulated declines in the Deh Sabz subbasin—1 to 3 m—were generally less than elsewhere in the Kabul Basin because this subbasin currently receives little direct recharge and no stream or irrigation leakage; therefore, total recharge is largely unchanged. Declines were least—less than 0.5 m—along the Panjsher River because the Panjsher River flows are large relative to leakage from the river. The simulated inflows from the large rivers, such as the Panjsher and Logar Rivers, were reduced; because the leakage from these inflows is relatively small in comparison to the total flow in the river, however, the reductions in recharge from river leakage were less apparent. Declines were relatively small, generally less than 0.5 m, along the Logar River and in groundwater-discharge areas such as the easternmost areas adjacent to the Kabul River in the Central Kabul subbasin.

The simulated groundwater declines caused by climate change would affect, to varying degrees, nearly all wells in the Kabul Basin. Of the wells affected, shallow supply wells would be most at risk. As indicated previously in this report, the groundwater in shallow supply wells is typically withdrawn less than 1 to few meters below the water table in the surficial aquifer. Based on simulated climate conditions, and in the absence of droughts or increasing withdrawals, 61 percent of existing shallow supply wells would undergo water-level declines of more than 0.5 m and 39 percent would undergo declines of more than 1 m. On the basis of the simulations, groundwater-level declines may cause about one quarter of all shallow supply wells to become inoperable either seasonally or over a long time period. The effects would be greatest near the base of the Paghman Mountains (Western Front Source Area) (fig. 31). The simulations showed that in the headwater areas of the Paghman and Upper Kabul and Shomali subbasins, more than 50 percent of shallow supply wells would become inoperable. On the basis of the simulations, anticipated increases in groundwater withdrawals by a larger population in the future would further increase the number of wells made inoperable as a result of potential climate change.

Summary and Conclusions

The United States (U.S.) U.S. Geological Survey (USGS) has been working with the Afghanistan Geological Survey (AGS) and the Afghanistan Ministry of Energy and Water (MEW) on water-resources investigations in the Kabul Basin under an agreement supported by the United States Agency for International Development (USAID). 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 describe Kabul Basin’s water resources. This report presents the results of a multidisciplinary assessment to address questions of future water availability in the presence of population growth and the potential impacts of climate change on the resources of the Kabul Basin. The 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 municipal and domestic and agricultural water uses. The data and analyses were integrated through a conceptual analysis by a groundwater-flow model for assessing current and future water availability.

Geomorphology and Geology

The Kabul Basin, Afghanistan, is in a northeast-trending basin-and-range setting bounded primarily by crystalline, and to a lesser extent, sedimentary rocks. The basin that forms the study area is filled by sand, silt, and gravel and encompasses about 3,600 km^2. The study area has been delineated into six subbasins based on local drainage divides: Central Kabul, Logar, Deh Sabz, Paghman and Upper Kabul, Shomali, and Panjsher subbasins. Additionally, two hydrologic zones of lesser extent are recognized on the basis of stable-isotope data—the Eastern and Western Front Source Areas along the eastern and western margins of the basin. Quaternary sands and gravels, generally less than 80 m thick, make up the primary surficial aquifer in the valley. Underlying Neogene sediments, consisting of a poorly sorted and semiconsolidated conglomerate of sand, silt, clay, and gravel 600 to about 1,000 m thick, compose a secondary aquifer.

Trends in Temperature and Climate

The climate of the Kabul Basin is arid to semiarid with cold winters and hot summers. Average annual precipitation in the Kabul Basin is approximately 330 mm/yr, whereas growing-season evapotranspiration rates are much higher.

Basinwide annual total recharge by infiltration of precipitation is probably about 30 mm. Mean monthly precipitation has historically been 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).

The Intergovernmental Panel on Climate Change, however, has identified patterns that include warming trends for southwest Asia, particularly over continental land masses. Increased surface temperatures in mountainous regions may affect the timing of snowmelt and reduce snowpack. During the next 50 years, a 10-percent reduction in total annual precipitation is anticipated in Afghanistan. Ongoing decadal climate change has been indicated by the reducted extents of glaciers in the Panjsher River watershed and the absence of glaciers in the Kabul River watershed in recent years. Comparisons of past (1961–1991) and recent (2003–2007) mean monthly temperatures show differences that may indicate warming throughout the year in the Kabul Basin. The greatest changes in mean monthly temperature from 1961 to 2007 occurred in February (+5°C) and March (+3°C). Analyses of vegetation patterns (Normalized Difference Vegetation Index) for the periods 1982–1985 and 1999–2002 indicate a shift in spring vegetation growth from April to March. This shift was followed by earlier vegetation senescence in June and July, indicating drier summer conditions in recent years.

Streamflow

The Kabul River watershed covers more than 25,500 km^2 upstream of and including the Kabul Basin study area; several large rivers flow into the study area and play a major role in the hydrology of the basin. Major tributaries include the Ghorband and Panjsher Rivers, which flow into and through the northernmost area of the basin with watersheds that cover approximately 4,000 and 3,500 km^2, respectively. Other major tributaries include the Kabul and Logar Rivers, which flow into and through the southernmost area of the basin, with watersheds that cover approximately 1,600 and 10,000 km^2, respectively. Small tributaries with drainage areas of 500 km^2 or less flow into the Kabul Basin from the Paghman Mountains to the west and from drainage areas to the north. Within the Kabul Basin study area, twelve streamgages were operated between 1959 and 1980. Fifteen to 20 years of daily streamflow record were collected at most of these streamgage sites. Analysis of historical mean annual and monthly runoff rates were used to calculate maximum and minimum flow rates and recurrence intervals. The average annual runoff per square kilometer of drainage area during the historical period of record was 0.020 m^3/s for the northern stations and 0.004 m^3/s for the southern stations. The watersheds to the north in the Hindu Kush Mountains are at a higher altitude and accumulate more precipitation, particularly snow, than the southern watersheds. The northern watersheds also include some glaciers. Because of their higher elevation and greater snow cover, the northern watersheds produce later peak discharges than the southern watersheds, which include the lower altitude Paghman and Dasht-i-Nawur Mountains. Three streamgages were reestablished in the study area in 2005, and one of these recorded streamflow data for the Panjsher River at Shukhi; however, trends cannot be defined from these limited data.

Flows for the Panjsher River at Shukhi for the 2006 water year, a year with near-normal precipitation, were compared to historical mean flows (for water years 1966 through 1980). Historically, the peak monthly flows had generally occurred during April in the southern watersheds and in June in the northern watersheds. The monthly mean peak flow for 2006 occurred in May as opposed to June during the period 1966–1980, and the 2006 summer flows were lower (the June flow was 36 percent lower, and the July flow was 54 percent lower) than flows in the mean historical record. This comparison of historical and recent records was cursory and did not identify trends between 1966 and 2006.

Groundwater Levels

Declines of a few meters to 10 m have been reported between the 1960s and early 2000s for some parts of the study area. Groundwater levels in the Kabul Basin have fallen dramatically as a result of below-normal precipitation in the early 2000s. The greatest declines in the early 2000s were measured in the central part of the city of Kabul in areas of increasing population. Since 2004, with more normal amounts of precipitation, some monitoring wells in rural areas have shown water-level increases of a few meters. The total population in the Kabul Basin was estimated to be approximately 3.5 million in 2002, with about 80 percent of the population in the city of Kabul, and is anticipated to increase by approximately 20 percent by the year 2012. To meet the increasing demand for water, approximately 1,500 shallow (water-table) domestic supply wells have been installed in recent years in the Kabul Basin, with the majority of these inside the city limits of Kabul. About 25 percent of these shallow supply wells, however, have been reported to be dry or inoperative. Based on United Nations projections, the population in the Kabul Basin is estimated to increase from about 3.3 million in 2007 to about 9 million by the year 2057. Projected increases in municipal and domestic water use associated with the anticipated population growth were simulated with a numerical model. The simulations showed water-level declines that may cause more than half of the shallow supply wells to become inoperative.

Water Quality

Seventy-seven surface-water samples were collected from 8 sites, and 92 groundwater samples were collected primarily from individual wells, springs, and karezes in the Kabul Basin in 2006 and 2007. Surface-water quality was not statistically different among the subbasins; the major ion chemistry was generally of the calcium-magnesium-bicarbonate type. Specific conductance of surface waters ranged from 67 to 1,497 µS/cm with a median value of 398 µS/cm. Nitrate concentrations ranged from 0.4 to 5.9 mg/L as N with a median of 1.7 mg/L. Total coliform and *E. coli* were detected in all stream samples. *E. coli* concentrations in excess of 2,420 colonies per 100 mL were detected in the Istalef River, the Kabul River in the Central Kabul subbasin, and at the Barik Ab River near Bagram.

The major ion chemistry of groundwater also was generally of the calcium-magnesium-bicarbonate type. The concentrations of many constituents in samples collected in the Central Kabul subbasin were higher than in samples from the other subbasins, and the samples often showed indications of anthropogenic contaminants. Samples from the Central Kabul and Deh Sabz subbasins and one sample from the Paghman and Upper Kabul subbasin consisted of a sodium-chloride-type water; other samples collected in the same subbasin also showed intermediate water compositions. The differing chemistries indicated mixtures of anthropogenic contaminants, constituents resulting from poor well construction, or increased concentrations of ions caused by water uptake by vegetation. In the Deh Sabz subbasin, higher concentrations of sodium and sulfate or chloride may be indicative of a transpiration rate by vegetation greater than elsewhere in the basin. In the study area, the specific conductance of groundwater ranged from 248 to 7,350 µS/cm with a median value of 799 µS/cm. In general, the conditions in the aquifer appeared oxic with dissolved oxygen concentrations ranging from 0.1 to 1.9 mg/L with a median value of 0.1 mg/L. Nitrate concentrations ranged from 0.6 to 40.2 mg/L as N with a median value of 3.3 mg/L as N. The highest nitrate concentration, 40.2 mg/L as N, was observed in samples from a well in the Central Kabul subbasin. Total coliform bacteria were detected in nearly all groundwater samples, and concentrations higher than 100 colonies per 100 mL were detected in six of the seven the subbasins. *E. coli* was detected in 97 percent of the groundwater samples; however, the concentrations of *E. coli* appeared to be randomly distributed in the basin. Concentrations of arsenic, lead, selenium, and uranium exceeded World Health Organization guidelines in 1, 3, 1, and 3 percent of the samples, respectively. Groundwater quality in the Kabul Basin is affected by anthropogenic activities, particularly in urban areas, where untreated wastewater and possible fertilizer applications remain of highest concern. The high rate of bacteria detections indicated that poor well-construction practices or wellhead contamination may be common.

Chemical and Isotopic Analysis

Considerable information concerning the hydrology of the Kabul Basin was determined from an analysis of chemical and isotopic data. On the basis of data on stable isotopes and mean-concentration ratios, much of the groundwater in the Kabul Basin appears to have infiltrated from surface water. Stable hydrogen and oxygen isotopic compositions were used to identify local rivers and streams as sources of groundwater recharge, with little surface water or groundwater evaporation. Groundwater sampled near the Paghman Mountains most likely was recharged from snowmelt and runoff from the mountains. Groundwater sampled in the Shomali subbasin most likely was recharged by leakage from tributaries to the Barik Ab River and flow diverted to irrigated areas. Some groundwater flows into the Kabul Basin at depth from adjacent mountains; however, this source of recharge most likely moves slowly and follows long flowpaths. Groundwater sampled near the eastern valley wall in the Deh Sabz subbasin had likely been recharged by inflows from the upland mountainous areas to the east, although little upland surface area drains to the Deh Sabz subbasin. The chemistry of sources of groundwater sampled in the Paghman and Upper Kabul, Central Kabul, and Logar subbasins was consistent with the chemistry of samples from the local-source rivers; this similarity indicated that infiltration from these rivers is a primary source of the groundwater.

The average ratios of mass concentrations of some dissolved major solutes (particularly Na and SO_4) to chloride in groundwater samples were similar to the same ratios in surface-water samples collected in the same subbasin. This result suggests that surface water is a predominant source for most of the groundwater sampled to depths of at least 650 m. Small variations in mass-concentration ratios for other solutes (particularly Ca, HCO_3, and to some extent Mg) indicate a lesser role for common water-rock reactions, including calcite precipitation and cation exchange in shallow groundwater. Solute concentrations in many of the groundwater samples exceeded those measured in surface water by factors of 100 or more. Because no evaporative signal was observed in the stable isotope data, the higher solute concentrations were attributed to the extraction of water by vegetation (transpiration) along the rivers and in surface-water drainage areas near irrigated crop land where plant-root systems can reach the water table. Transpiration removes water without altering the stable isotopic composition of the residual water; thus, the solutes are concentrated without a detectable shift in stable isotopic composition.

Chlorofluorocarbon (CFC)-12 volume fractions in most of the groundwater samples were consistent with recharge by post-1970s water. Leakage of saline waters into the basin as a source of the high solute concentrations is unlikely on the basis of the measured tritium and CFC concentrations and cation/anion mass ratios. On the basis of the chemical, stable isotope, and environmental tracer data, the infiltration of surface water, with subsequent concentration through uptake of water by vegetation in irrigated areas, is the most likely source of recharge for most of the groundwater sampled throughout the Kabul Basin as part of this study.

The CFC analysis permitted estimation of the age and fraction of young to old groundwater for some samples. Depending on the particular CFC ratios assessed, the average age of the young component of groundwater in the study area was about 16 to 21 years. Young groundwater composed about 58 to 76 percent of the water in the samples, and the groundwater was unmixed in more than half of the groundwater samples tested. The average ages of groundwater in the subbasins differed slightly depending on the CFC analysis method used but were approximately 20 years in the Paghman and Upper Kabul subbasin, 28 years in the Deh Sabz and Central Kabul subbasins, and 15 to 19 years in the Shomali subbasin. The CFC data indicate that groundwater age increased with depth, and that the fraction of young water in groundwater mixtures pumped from wells decreased somewhat with depth. On the basis of the interpreted CFC ages and the depths at which samples were collected below the water table, basinwide recharge rates were estimated to be 0.4 to 0.8 m/yr, and 0.35 to 0.7 m/yr for assumed porosities of 30 and 25 percent, respectively. These estimates of recharge included irrigated areas, where infiltration of irrigation water may have contributed a large portion of the local recharge.

Water Use

The per capita water-use rate in the Kabul Basin was assumed to increase from about 11 to 15 m^3/yr in 2007 to about 78 m^3/yr by 2057. Based on the assumed population and water-use increases, municipal and domestic water use in the Kabul Basin was estimated to increase from approximately 112,000 in 2007 to 725,000 m^3/d annually by 2057, or about six times the current use.

Agricultural water use occurs primarily in three areas of the Kabul Basin. 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 costs; irrigation water 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 subbasin, 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. The total water used seasonally by crops, the actual evapotranspiration, has been estimated to be more than 1,300 mm in the Shomali subbasin. The total annual agricultural water use in the Kabul Basin is likely to be an order of magnitude greater than the total annual domestic water use. Irrigation efficiency may be as low as about 50 percent as a result of evaporation losses and infiltration at leaking canals. In the irrigated areas, inflows to the basin are redistributed, and a portion of the inflow infiltrates to underlying aquifers. With increasing population, the need for irrigation water can be expected to increase. In some areas of the Kabul Basin that are supplied by small tributaries or ephemeral streams, such as southern areas of the Shomali subbasin and the Deh Sabz subbasin, increases in irrigated extent may not be possible.

Conceptual Groundwater-Flow Simulation

The groundwater-flow system was investigated conceptually by constructing a simplified steady-state groundwater-flow model. This model was used to account for and estimate the components of groundwater flow in the Kabul Basin. Geological information was provided by previous investigations and collaborative work between the USGS and the AGS. The conceptual model was calibrated to historical streamflow and water-level information compiled by this investigation and to recent water levels measured during the AGS and USGS collaboration.

The surficial aquifer in the conceptual model of the Kabul Basin consists of highly permeable, coarse-grained sands and gravels adjacent to the major river channels and finer-grained windblown sediments covering most of the valley floor. The coarse-grained sediments adjacent to river channels form the primary surficial aquifer, in which the larger municipal wells have been completed. Many shallow supply wells have been installed in sediments throughout the basin. The surficial sediments are underlain by older, weathered Neogene sediment and bedrock approximately 600 to 1,000 m thick. The quality of the water in this secondary aquifer is largely unknown, but the water is thought to be older than the groundwater in the primary aquifer and to contain a higher concentration of dissolved solids. The basin-fill sediments are bounded primarily by crystalline and metamorphic bedrock and lesser amounts of sedimentary rock that form the basin walls and interbasin ridges. The bedrock has little primary porosity and contains groundwater in fractures. Groundwater storage may be higher in areas where the bedrock is more highly fractured, such as the Paghman Mountain front, where groundwater from the surrounding upland areas may flow to the subbasin aquifers. The potential water availability is greater in these areas—the northern and western areas of the basin—than elsewhere in the Kabul Basin.

The primary, or shallow, surficial aquifer is recharged by winter and spring precipitation and leakage from rivers and irrigated areas. The mean annual rate of recharge through infiltration of precipitation directly through the subbasin sediments was estimated to be about 0.0004 m/d. Surface-water inflows through streamflow leakage, drainage from upland areas, or irrigation leakage may contribute about 0.0012 m/d of recharge annually to some areas of the Kabul Basin; this amount of recharge is greater than the infiltration of precipitation. Therefore, the total annual recharge differs widely with location in the Kabul Basin, may originate from a combination of sources, and may be as much as 0.8 m/yr, as indicated by the results of the isotopic analysis. In the eastern areas of the Kabul Basin, direct recharge is likely to be near zero.

Streamflow leakage likely contributes large amounts of recharge near stream channels during periods with sustained streamflows. Perennial streams draining upland areas at the basin flanks form a source of surface-water inflow to the valley that may be considerable depending on the size of the adjacent upland area. Recharge by streamflow leakage, however, is limited by the rate at which water can infiltrate the streambed. During periods of low flow, most of the flow may infiltrate to underlying aquifers; however, during periods of high flow, most of the flow may bypass the aquifer system. Irrigation likely enhances natural surface-water infiltration and thus increases recharge by providing a greater surface area. Irrigated areas may also provide a mechanism for capturing a portion of the flow that, without the additional surface area, would bypass the valley. The volume of water used by crops, however, is the largest of all the water-use types in the Kabul Basin; this water is a loss from the flows leaving the Kabul Basin. In northern areas of the basin, streamflow diversions for irrigation draw water from the Panjsher River and its tributaries. In the Shomali subbasin, irrigation water is obtained from tributaries draining the Paghman Mountains. In the southern areas of the Kabul Basin, including the Central Kabul, Logar, and Paghman and Upper Kabul subbasins, irrigation water is supplied by the Kabul, Paghman, and Logar Rivers. The Deh Sabz subbasin supports very little irrigation and therefore produces little additional recharge, because there are no perennial rivers flowing into or through this area. Additionally, upland watershed areas in the Deh Sabz subbasin and other eastern areas of the Kabul Basin are too small to produce additional surface-water drainage or lateral groundwater inflow into the subbasin. As a result, total recharge to the study-area subbasins and water availability vary considerably and primarily depend on proximity to a sustained surface-water source, such as streams and irrigated areas; proximity to upland areas with perennial or intermittent streams; and proximity to upland areas that contribute lateral groundwater inflows through adjacent bedrock.

The groundwater-flow model developed for this study was used to account for and estimate the components of groundwater flow in the Kabul Basin. Water leaves the Kabul Basin primarily as streamflow discharge in the Panjsher and Kabul Rivers. The total annual base flow in the Panjsher River and its tributaries was about six times that of the Kabul River. In the southern part of the study area, the average annual base flow at the Kabul River outflow point at Tang-i-Gharu was approximately equal to the base flows in the major rivers entering the basin (the Paghman, Kabul, Logar, and Chakari Rivers). In the northern part of the study area, the sum of the average annual base flows for the major rivers entering the basin (the Panjsher, Ghorband, Salang, and Shatul Rivers) was greater than the base flow at the Panjsher River outflow point at Shukhi. Unmeasured groundwater inflows to the Kabul Basin from upland areas would also increase the likelihood of negative balances at the two outflow-measurement stations. The negative balance indicates that consumptive water uses, actual evapotranspiration (irrigation water use), and evapotranspiration were important components of the water balance of the study area.

Water Availability

The population in the study area, which included the city of Kabul and surrounding areas, was 3.3 million in 2007 and has been growing at a rate of about 4 percent a year during the past 5 years. Population estimates were not available for 2057; however, high growth rates are expected to continue, and a population of 9 million was estimated for the purposes of this study for the Kabul Basin in 2057. The municipal and domestic water-use rate was estimated to increase about sixfold from the current (2007) rate by 2057 because of population growth and increasing rates of per capita water use. The total water-use rate for the entire Kabul Basin was estimated to increase from about 112,000 to 725,000 m^3/d by 2057.

Based on simulations, groundwater supplies are expected to be available in the primary surficial (Quaternary) aquifer during years of normal amounts of precipitation, with the greatest relative water availability in areas that receive recharge by streamflow infiltration or upland drainage at the valley flanks. Water resources are limited in other areas such as the Deh Sabz subbasin or southeastern parts of the Shomali subbasin. During years with below-normal amounts of precipitation, such as the early to mid-2000s, the surficial aquifer becomes stressed and groundwater levels decline in shallow wells. Simulations of a sixfold future increase in groundwater withdrawals from the surficial aquifer indicated that during years with normal amounts of precipitation, groundwater levels in the central areas of those subbasins with major population centers may decline by 1–2 m in less urban areas and as much as 40 m in urban areas. On the basis of the simulations, many wells will not provide an adequate supply of water in more densely populated areas because the mean depth of small community wells installed in recent years is 20 m. Simulated future water-level declines indicate that more than half of the current shallow supply wells may likely become inoperative.

The Neogene aquifer is currently not used as a source of water in the Kabul Basin. Because of its considerable thickness, the Neogene aquifer stores more water than the overlying surficial aquifer but has not been used because of its low permeability and questionable water quality. Some previous and recent investigations, however, have found evidence of coarse-grained lenses within the Neogene aquifer. If such lenses can be located and are locally extensive, it may be possible to withdraw groundwater at rates sufficient for municipal use. If the lenses are not regionally extensive, well yields are likely to be limited because of the low permeability of the aquifer, and multiple extraction wells would likely be necessary to meet municipal needs. It may be possible, however, to maintain sustained withdrawals from the Neogene aquifer with minimal effect on water levels in the surficial aquifer. Withdrawals from the upper Neogene aquifer may affect water levels in the surficial aquifer less directly than withdrawals in the surficial aquifer itself and may possibly be sustained by regional sources of recharge. These withdrawals in the upper Neogene aquifer may not directly capture river water but would likely still cause groundwater declines in the surficial aquifer and induce inflows from nearby rivers and other surface-water sources. Withdrawals from the Neogene aquifer, however, may require treatment for high salinity or dissolved solids. The age, or residence time, of groundwater in the Neogene aquifer (thousands of years old) is likely to be one or two orders of magnitude greater than that of groundwater in the surficial aquifer and to differ among subbasin areas. This variability may have implications for the quality and sustainability of this resource. The sustainability of groundwater in the Neogene aquifer in subbasin areas like the western part of the Central Kabul subbasin, which is bounded by interbasin ridges, may be much less than that of the groundwater in the Neogene aquifer in the northern and western areas of the Kabul Basin, which are bounded by large mountains.

In addition to an increasing demand for water, future climate change is a concern for the residents of the Kabul Basin. Although considerable uncertainty is associated with climate-change projections, the climate-change forecast for 2057 may include a 10-percent reduction in total annual precipitation; as simulated in this study, this reduction would reduce all inflows and exacerbate currently stressed water resources. Increasing temperatures would likely shift peak spring runoff to an earlier period during the year. Currently, most annual recharge occurs in the spring and late winter; however, an earlier peak recharge period would shift water resources ahead of the summer period, when water is most needed, and thus extend the summer dry period. The larger rivers flowing into the basins may still supply considerable recharge to the Kabul Basin; however, if irrigation is reduced because of low flows, the decline in direct recharge from rainfall and stream leakage may be compounded by reduced irrigation recharge. Reductions in recharge may be slight in areas near the larger rivers, such as areas adjacent to the Panjsher and Ghorband Rivers to the north and the Kabul and Logar Rivers to the south. In other areas that receive a large component of recharge from local uplands, such as areas in the Paghman River watershed and the Shomali subbasin (which includes the Barik Ab River watershed), the effect of climate change on water resources may be more critical. The Deh Sabz subbasin currently receives very little direct recharge and no recharge from irrigation; as a result, reductions in precipitation may affect this subbasin less than other subbasins. The Central Kabul subbasin, particularly the northwestern part, also receives very little recharge; however, with an increased demand for water, the effects of climate change on the hydrologic system in this area would likely be pronounced. Simulated groundwater-level declines indicate about one-quarter of all shallow supply wells may become inoperable. Simulated declines are predicted to be greatest near the base of the Paghman Mountains (in the Western Front Source Area). In the headwater areas of the Paghman and Upper Kabul and Shomali subbasins, simulations indicate that more than 50 percent of shallow supply wells may become inoperable.

In conclusion, the Kabul Basin has an immediate and growing need for water, yet available supplies may be adversely affected by future climate change. In some areas of the basin, water supplies are adequate, but the water quality has deteriorated because of poor sanitation and poor well-construction practices. The basin likely has considerable groundwater reserves in deep, currently unused aquifers that may be sustainable for municipal and domestic use but not for agricultural use. The hydraulic feasibility of groundwater extractions and the quality of groundwater in the deep aquifer, however, are unknown. This investigation was intended to provide data, analysis, and tools needed for planning for the future water resources of the Kabul Basin. Additional investigations would be needed, however, to assess the utility of water resources in the deep aquifer for future supply, to monitor water-level and quality conditions over time, and to assess for changes in water availability over time.

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Appendix 1. Climate

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Satellite rainfall estimates were used as a key input to an energy-balance model for simulation of snowpack accumulation and depletion. The NOAAs Climate Prediction Center (CPC) provides gridded precipitation estimates at 0.1 degree resolution (RFE 2.0) that blend satellite and station observations using geostatistical methods (Xie and Arkin, 1997). Satellite inputs include thermal infrared imagery from geostationary weather satellites, typically acquired every 30 minutes, and passive microwave imagery acquired several times a day by polar orbiting satellites. The thermal infrared data provide a measure of cloud-top temperatures, which are correlated with the occurrence of rainfall. The microwave imagery detects upwelling radiation that has been scattered by the presence of precipitation-sized ice particles in the cloud layer. Station data are accessed through the Global Telecommunication System (GTS) of the World Meteorological Organization (WMO). These are a relatively small subset of rainfall station data collected by the national meteorological services of United Nations (UN) member countries. (Theoretically, over 4,000 stations are part of the GTS reporting network in the Central Asian RFE domain, but on any given day, only about 500 stations report. No station data from within Afghanistan are entered into the GTS. Only surface observations from neighboring countries are available to reduce bias in the RFE 2.0 estimates for Central Asia.) Precipitation estimates from thermal infrared imagery and microwave imagery are blended using weights that are inversely proportional to the error of each type of imagery. Then interpolated station data are used to remove bias from the blended satellite rainfall estimate field, while retaining its shape and form. NOAA/CPC has produced precipitation estimates of 24-hour accumulations for Afghanistan operationally each day since 2003.

A distributed version of the Utah Energy Balance Accumulation and Melt Model (UEB) (Tarboton, 1994; Tarboton and others, 1995) was used for the study. The snow water equivalent (SWE) model is a spatially distributed snowmelt model driven with remotely sensed and assimilated meteorological data. The UEB uses a lumped representation of the snowpack with two primary state variables, namely water equivalence (or total amount of water, expressed in depth (mm), in the snowpack), and energy content relative to a reference state of water in the ice phase at 0˚C. This version of the model runs in a spatially distributed mode using a grid resolution of 10 km. The UEB uses physically based calculations of the radiative, sensible, latent, and advective heat exchanges (i.e., exchanges, or fluxes, of energy resulting from incoming and outgoing short- and long-wave radiation, thermal or heat conduction, evaporation and condensation, and horizontal heat transport). An equilibrium parameterization of snow-surface temperature accounts for differences between snow-surface temperature and average snowpack temperature, without having to introduce additional state variables. Melt outflow is a function of the liquid fraction and is parameterized according to Darcy's law. This parameterization allows the model to account for continued outflow even when the energy balance is negative. It was not possible to carry out snowmelt model parameter calibration for Afghanistan because of the lack of direct observational data. Instead, parameters from the calibration of Tarboton and Luce (1996) using data from the Central Sierra Snow Laboratory were used.

The UEB was forced using RFE 2.0 precipitation and output fields from two operational atmospheric models: NOAAs Global Data Assimilation System (GDAS) and the Air Force Weather Agencys MM5. GDAS provided radiation fields, and the MM5 provided surface air temperature, wind, humidity, and atmospheric pressure. The six-hourly meteorological variable fields were downscaled to match the 0.1 degree resolution of the RFE 2.0 using the USGS GTOPO30 digital elevation database. The GTOPO30 is a global topographic data set (Gesch and others, 1999) with a spatial resolution of 30 arcseconds (about 1 km), well suited to downscaling the GDAS (1.0 degree, about 100 km) and MM5 (45 km) fields to the 0.1 degree grid used for the UEB. The MODIS Snow Cover Daily L3 Global (MOD10A1) data set (Hall and others, 2000), at 500-m resolution, was compared with the UEB simulated snow-cover extent for Afghanistan as a check on model performance. (MODIS snow-cover data are distributed by the National Snow and Ice Data Center (NSIDC) DAAC in Boulder, Colo.)

The UEB produced daily national grids of snow-water equivalent (SWE) at 0.1 degree resolution (fig. 1-1) for the period October 1, 2002, through August 24, 2007, characterizing five winter seasons. Basin areas above the Tang-i-Gharu streamgage on the Kabul River and the Shukhi streamgage on the Panjsher River were delineated from GTOPO30 using ArcGIS. These polygons were used to produce daily values of total snow-water volume above each of the two streamgages for the five winter seasons.

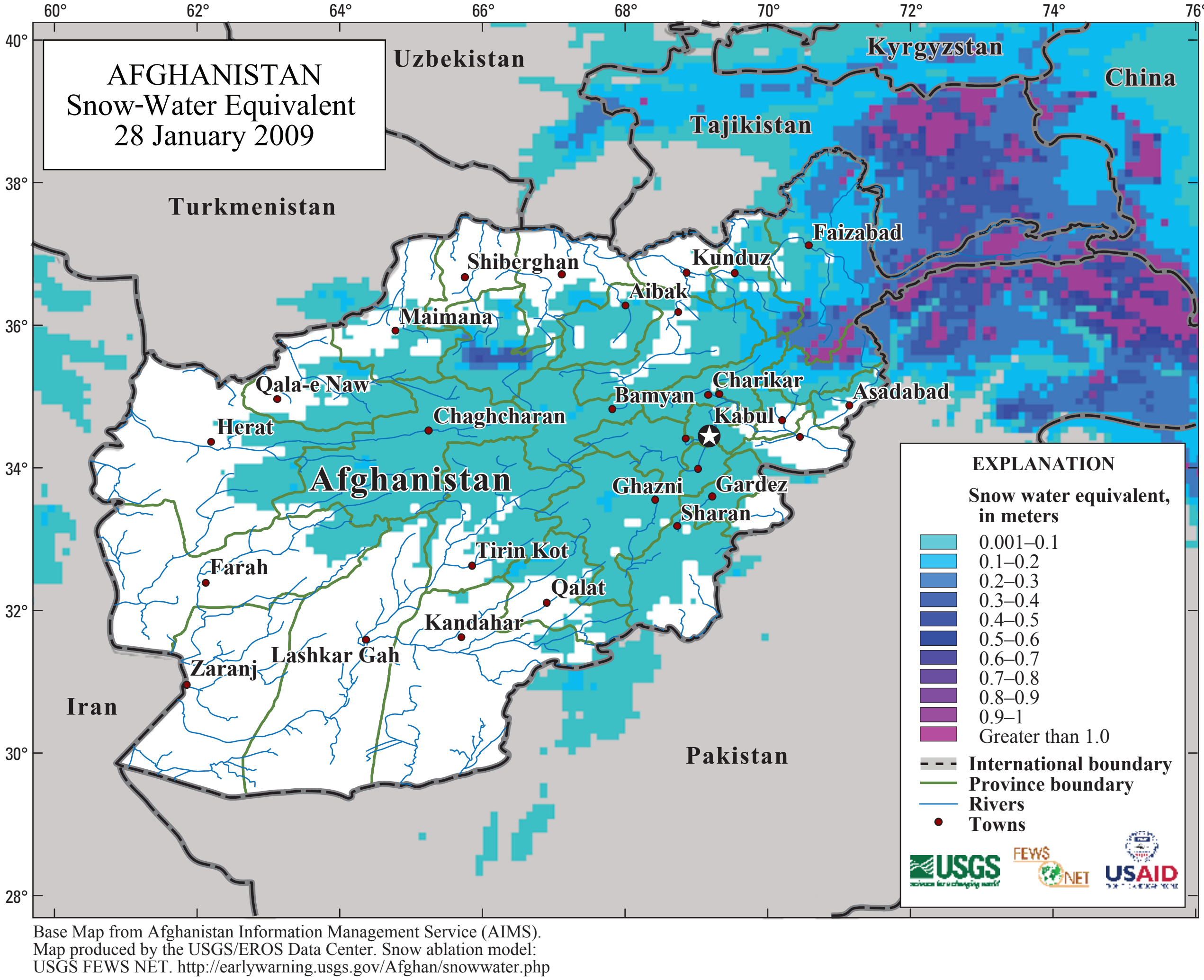

Figure 1-1. Daily national snow-water equivalent grid produced with the Utah Energy Balance Accumulation and Melt Model (Tarboton and Luce, 1996) at 0.1 degree resolution.

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Appendix 2. Geomorphology Methods

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Appendix 2. Geomorphology Methods

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) measures reflected radiation in three bands between 0.520 and 0.860 µm (visible-near-infrared region–VNIR) and in six bands from 1.00 to 2.43 µm (short-wave infrared region–SWIR), with 15-m and 30-m spatial resolution, respectively (Fujisada, 1995). In addition, ASTER measures emitted thermal radiation in five bands in the 8.125- to 11.650-µm wavelength region (thermal-infrared–TIR) at 90-m resolution (Fujisada, 1995). Standard ASTER data products (VNIR-SWIR reflectance, TIR emissivity, and TIR decorrelation stretch products) and (or) their equivalents were used in this study. For example, a false-color composite image of ASTER bands 6, 3, and 1, displayed as red, green, and blue, respectively, is shown in figure 2-1A. This image represents a mosaic of three ASTER scenes from a single 60-km wide orbital swath, which covers more than 95 percent of the Kabul Basin and MODFLOW study area, and was acquired on October 12, 2001. Similar to a Landsat TM 7-4-2 color composite, vegetation appears green and dominates the land-use/cover pattern of much of the northernmost Shomali subbasin, which is irrigated and intensively cultivated using a one-crop per year rotation system. Basin-fill alluvial sediments reflect a bright white color in this ASTER band combination and notably dominate the Deh Sabz subbasin; built-up and impervious areas of Kabul and its suburbs appear dark blue and dominate the Paghman and Upper Kabul and Central Kabul subbasin. Eolian materials and hardpans (e.g., ferricrete, calcrete, and (or) silcrete) appear variously colored, but the former displays recognizable dune and wind-streak patterns in the visible ASTER bands for areas east of the Barik Ab tributary of the Panjsher River in the northeastern portions of the Shomali subbasin dominated by rangeland and pasture land-use types, bare soils, and rock outcrops.

A mosaic of three decorrelation stretch images of ASTER TIR bands 13, 12, and 10, displayed as red, green, and blue, respectively, is shown in figure 2-1B. Because ASTER decorrelation images distributed by the Eros Data Center are “standard products” generated on a scene-by-scene basis, histogram matching was done in order to facilitate generation of a “seamless” mosaic along this single orbital swath of ASTER data. However, the high degree of compositional variability in the northern portion of the Shomali subbasin created statistical problems in effectively matching brightness values between overlapping areas within the upper and middle ASTER scenes. This problem produced a notable seam that only affects the basin-fill alluvial areas of the Shomali subbasin, but not the surrounding bedrock and vegetated areas (fig. 2-1B). Decorrelation stretch images are used to enhance the brightness variations between TIR bands related to compositional differences in emissivity, while suppressing correlated inter-channel brightness related to variations in radiant temperature (Gillespie and others, 1986). In this case, compositional variations are due largely to relative abundances of silica-rich minerals (mostly quartz), which appear red, mafic minerals (e.g., pyroxenes and amphiboles), which appear blue, and carbonate minerals and vegetation, both of which appear green. Mixed colors are largely the result of mixtures between these three basic mineral types. For example, purple areas dominate alluvial fans derived from mafic-rock source areas in the western portions of the Shomali subbasin (fig. 2-1B) because these rocks tend to weather more rapidly to produce clay- and ferric-iron rich soils that are commonly enriched in residual silica (Kahle and others, 1988). Notably, such color variations displayed in TIR decorrelation stretch imagery can be used to determine relative ages, assuming constant rates of weathering (Kahle and others, 1988). The rates of weathering in a high-desert environment such as Afghanistan are likely to be too slow and on geologic time scales to impact the chloride concentrations in groundwater.

Chlorophyll-bearing vegetated areas have been masked out of the decorrelation stretch image on the basis of a thresholded band-ratio image of ASTER VNIR bands 3/2; thus, these areas appear black (fig. 2-1B). Although this is an effective method for masking green vegetation and built-up urban areas, which typically contain mixtures of impervious surfaces and green vegetation (Ridd, 1995), this band ratio is ineffective for mapping dry vegetation with little or no chlorophyll. Therefore, dry vegetation and carbonate minerals can be confused if spectral mapping is based solely on ASTER SWIR or TIR data alone. However, carbonate minerals yield stronger absorption features in ASTER SWIR band 8 and ASTER TIR band 14 than dry vegetation containing lignin and cellulose (Murphy, 1995), which allows for the use of band-ratios and relative band-depth images with conservative thresholds as a solution in order to emphasize areas of highest abundance and probability of occurrence for carbonate minerals (Murphy, 1995).

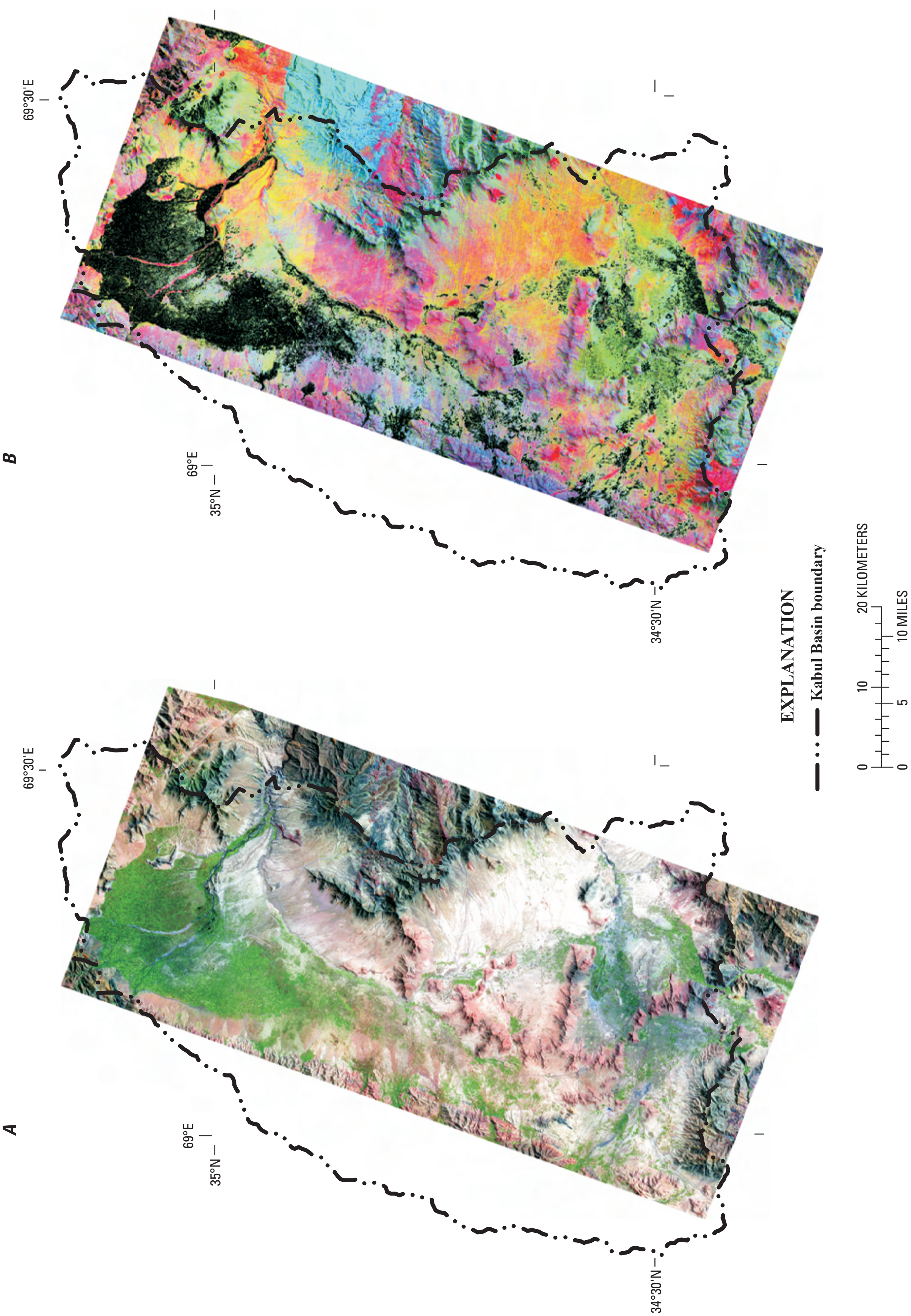

Figure 2-1. (A) False-color composite of ASTER bands 6, 3, and 1 displayed as red, green, and blue, respectively; and (B) a mosaic of three decorrelation stretch images of ASTER TIR bands 13, 12, and 10 displayed as red, green, and blue, respectively, for the Kabul Basin, Afghanistan.

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Appendix 3. Surface Water

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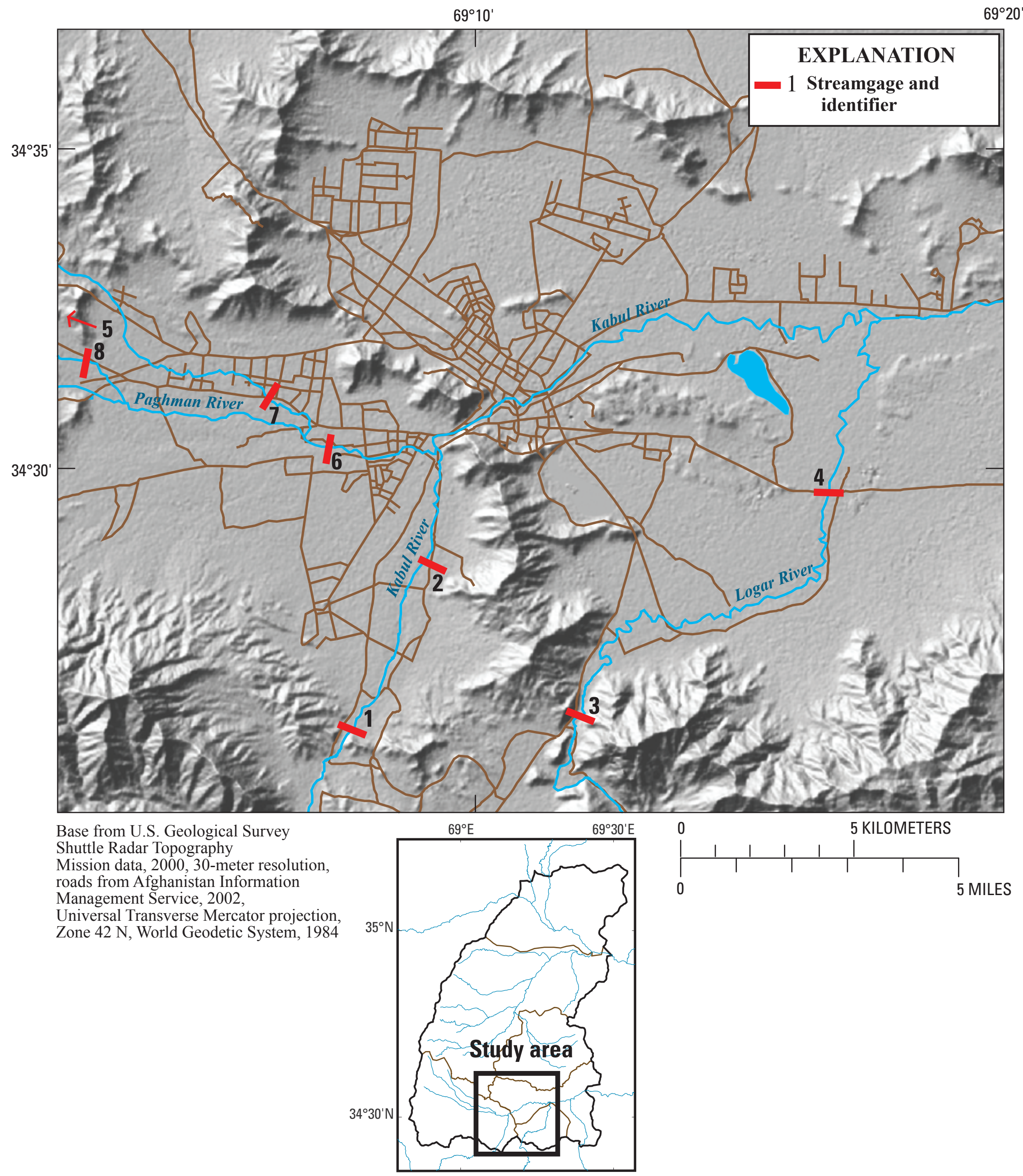
Appendix 3. Surface Water

Böckh (1971) provides streamflow data for eight streamgages in the vicinity of the city of Kabul for the 1963 water year (fig. 3-1, tables 3-1 through 3-7). This information is reproduced here to make it available and to illustrate the importance of stream and aquifer interactions in the Kabul Basin. Böckh (1971) used streamflow data to evaluate the gains and losses to the rivers between the selected streamgages. Streamgages 1 and 2 are on the Kabul River as the river enters the city of Kabul from the south. Streamgages 3 and 4 are on the Logar River southeast of the city of Kabul and just before the Logar River enters the Kabul River. Streamgages 5, 6, 7, and 8 are on the Qargha (Karga) and Paghman Rivers just west of the city of Kabul.



Base from U.S. Geological Survey Shuttle Radar Topography Mission data, 2000, 30-meter resolution, roads from Afghanistan Information Management Service, 2002, Universal Transverse Mercator projection, Zone 42 N, World Geodetic System, 1984

Figure 3-1. Location of streamgages at which runoff and water losses are provided by Böckh (1971). Streamgage numbers and locations are based on map plates from Böckh (1971).

Table 3-1. Discharge between streamgages 1 and 2.

[See figure 3-1 (modified from Böckh,1971)]

Year	Month	Discharge, in cubic meters per second		
		Streamgage 1	Streamgage 2	Water gain or loss (-)
1962	October	0.65	[1]0.26	0.39
	November	1.17	[1]0.35	0.82
	December	1.84	0.74	1.10
1963	January	2.81	1.59	1.22
	February	2.07	1.09	0.98
	March	1.70	0.75	0.95
	April	6.55	5.20	1.35
	May	22.50	17.20	5.30
	June	6.56	5.05	1.51
	July	0.64	0.26	0.38
	August	0.59	0.17	0.42
	September	0.51	0.18	0.33
Annual mean		3.97	2.74	1.23

[1] Computed from discharge at Streamgage 1.

Table 3-2. Annual discharges and losses for streamgages 1 and 2, 1963 water year.

[See figure 3-1 (modified from Böckh, 1971). Maximum runoff (river plus channels) is 45.5 cubic meters per second May 15 and 19, 1963. Minimum runoff (river plus channels) is 0.34 cubic meter per second August 17, 1963]

	Discharge, in millions of cubic meters		
	Streamgage 1	Streamgage 2	Water loss
River	96.5	71.1	25.4
Channels	27.5	14.3	13.2
Total discharge	124.0	85.4	38.6

Table 3-3. Discharge differences between streamgages 1 and 2 for selected periods.

[See figure 3-1 (modified from Böckh, 1971)]

Periods	Discharge, in cubic meters per second					
	Streamgage 1		Streamgage 2		Water loss	
	River	Channel	River	Channel	River	Channel
April - June	10.70	1.20	8.41	0.73	2.29	0.47
July - November	0.08	0.63	0.00	0.25	0.08	0.38
December - March	1.15	0.97	0.42	0.63	0.73	0.34
Annual Mean	3.10	0.87	2.25	0.49	0.85	0.38

Table 3-4. Discharge between streamgages 3 and 4.

[See figure 3-1 (modified from Böckh, 1971)]

Year	Month	Discharage, in cubic meters per second		
		Streamgage 3	Streamgage 4	Water gain or loss (-)
1962	October	5.78	[1]4.58	-1.20
	November	12.00	[1]12.5	0.50
	December	15.80	[1]16.7	0.90
1963	January	16.00	17.60	1.60
	February	14.80	16.00	1.20
	March	12.90	13.90	1.00
	April	8.40	7.85	-0.55
	May	20.50	21.40	0.90
	June	2.11	0.57	-1.54
	July	1.89	[1]0.55	-1.34
	August	1.62	[1]0.41	-1.21
	September	1.78	[1]0.39	-1.39
Annual mean		9.47	9.37	-0.10

[1] Discharge diverted to the Kabul River was added.

Table 3-5. Annual discharges and losses for streamgages 3 and 4, 1963 water year.

[See figure 3-1 (modified from Böckh, 1971). Maximum runoff (river plus channels) is 50.0 cubic meters per second May 13, 1963. Minimum runoff (river plus channels) is 1.50 cubic meters per second September 8, 1963.]

	Discharge, in millions of cubic meters		
	Streamgage 3	Streamgage 4	Water loss
River	231.8	227.0	4.8
Channels	67.7	65.5	2.2
Total discharge	299.5	292.5	7.0

Table 3-6. Discharge differences between streamgages 3 and 4 for selected periods.

[See figure 3-1 (modified from Böckh, 1971)]

Periods	Discharge, in cubic meters per second					
	Streamgage 3		Streamgage 4		Water gain or loss (-)	
	River	Channel	River	Channel	River	Channel
October - November	5.94	2.95	6.90	1.64	0.96	-1.31
December - March	13.30	1.60	12.80	3.30	-0.50	1.70
April - May	11.80	2.60	11.00	3.60	-0.80	1.00
June - September	0.15	1.70	0.18	0.30	0.03	-1.40
Annual mean	7.43	2.04	7.28	2.09	-0.15	0.05

Table 3-7. Discharge between streamgages 5, 7, and 8, and 6.

[See figure 3-1 (modified from Böckh, 1971); --, no data]

Year	Month	Discharge, in cubic meters per second					
		Streamgage 5[1]	Streamgage 7[2]	Streamgage 8[3]	Sum of streamgage 5, 7, and 8	Streamgage 6[4]	Water gain or loss (-)
1962	October	0.03	0.00	0.00	0.03	0.00	-0.03
	November	0.03	0.00	0.00	0.03	0.01	-0.02
	December	0.03	0.00	0.00	0.03	0.29	0.26
1963	January	0.04	0.13	0.00	0.17	0.37	0.02
	February	0.04	0.11	--	0.15	0.15	0.00
	March	0.02	0.05	1.12	0.19	0.22	0.03
	April	0.10	0.00	1.06	1.16	0.67	-0.49
	May	1.92	0.26	3.61	5.79	3.77	-2.02
	June	0.37	0.00	0.06	0.43	0.07	-0.36
	July	0.19	0.00	0.05	0.24	0.01	-0.23
	August	0.10	0.00	0.02	0.12	0.00	-0.11
	September	0.05	0.00	0.02	0.08	0.01	-0.08
Annual mean		0.24	0.05	0.41	0.70	0.46	-0.24

[1] Paghman River plus channel.

[2] Qargha (Karga) River.

[3] Cheltan River plus channel.

[4] Paghman River which is downstream of streamgages 5, 7, and 8.

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Appendix 4. Chemical and Isotopic Analysis of Air and Water Samples

Contents

Appendix 4. Chemical and Isotopic Analysis of Air and Water Samples

Chemical and isotopic data collected for this investigation included measurements of (1) the stable hydrogen and oxygen isotopic composition of surface water and groundwater, (2) the major and minor-element chemical composition (30 elements) of surface water and groundwater, (3) the dissolved gas compositions of surface water and groundwater including dissolved nitrogen, argon, carbon dioxide, oxygen, methane, helium, and the chlorofluorocarbons (CFCs, CFC-11, CFC-12, and CFC-113), (4) the chlorofluorocarbon composition of air samples, and (5) the tritium content of surface water and groundwater.

Air Samples

Ambient air samples were collected in 500-cc stainless steel vessels that were evacuated in the laboratory and opened at the collection site. The valves were then closed, and the vessels were returned to the U.S. Geological Survey (USGS) Reston Chlorofluorocarbon Laboratory for analysis. Two separate vessels were filled at each site, and each vessel was analyzed in duplicate by gas chromatography with an electron-capture detector (see *http://water.usgs.gov/lab/cfc*); laboratory precision was approximately 5 percent.

Water Chemistry

Samples for cation analysis were collected in acid-rinsed 250-mL polyethylene bottles. The samples were filtered in the lab and acidified with 2 mL of Ultrex nitric acid. The samples for anion analysis were filtered and collected in 250-mL polypropylene containers. The containers were obtained from the USGS Water Quality Laboratory.

Major cations and silica were analyzed at the USGS Water Chemistry Laboratory in Reston, Va., using the Perkin-Elmer Optima DV 4300, a dual view inductively coupled plasma optical atomic emission spectrometer (ICP-OES). The detection limits for mass concentrations of Ca, Mg, SiO_2, Na, and K by ICP-OES were less than 0.05, 0.05, 0.1, 0.05, and 0.1 mg/L, respectively. Precision for measurements of Ca, Mg, SiO_2, Na, and K mass concentrations by ICP-OES was 1 to 3 percent.

Trace cations were analyzed using a Perkin Elmer ELAN6000 inductively coupled plasma mass spectrometer (ICP-MS) with a Scott-type cross-flow nebulizer for sample introduction and a quadrupole mass separator. The detection limits for mass concentrations of As, Ba, Cu, Mo, Ni, Rb, Sb, and V were 0.1 µg/L. The detection limits for mass concentrations of Al, Cr, Li, Mn, Se, Sr, and Zn were 1 µg/L. The detection limits for mass concentrations of Cd, Pb, and U were 0.05 µg/L. The detection limits for mass concentrations of B and Fe were 0.02 µg/L. Precision was generally 1 to 3 percent for all elements analyzed by ICP-MS.

A Dionex series DX-120 equipped with Dionex AS14 (analytical) and AG-14 (guard) columns was used for the analysis of fluoride, chloride, bromide, nitrate, and sulfate. Detection limits for mass concentrations of chloride, sulfate, nitrate, bromide, and fluoride were less than 0.2, 0.2, 0.1, 0.05, and 0.05 mg/L, respectively. The precision for measurements of chloride, sulfate, nitrate, and bromide was 1 to 3 percent. The precision for measurements of fluoride was 3 to 5 percent.

Alkalinity was measured in the USGS Water Chemistry Laboratory using a Radiometer TIM900 titration manager and ABU93 autoburette. Some bicarbonate may have been lost between the time the samples were collected and when they were analyzed in the laboratory, as was evidenced by calcium carbonate precipitates in some sample bottles collected in 2006 (samples from karez 10 and 69, spring 67 and 181, and well 28, 33, 42, 47, 172, 203, and 208). For these, alkalinity was estimated using a charge-balance algorithm. The mass concentration detection limit of bicarbonate for alkalinity titrations was 2 mg/L. The precision for alkalinity titrations was approximately 1 percent.

Major Dissolved Gases

Water samples for analysis of major dissolved gases were collected in 150-cc septum bottles without headspace. Mass concentrations of N2, Ar, O2, CO2, and CH4 were measured in the USGS Dissolved Gas Laboratory, Reston, Va., using gas-chromatographic procedures (*http://water.usgs.gov/lab/cfc/*). Replicate analyses of N2 and Ar in laboratory standards prepared by equilibrating water samples with air were typically within 1 percent and yielded calculated equilibration temperatures within ± 0.5°C. The dissolved O2 and CO2 analyses have uncertainties similar to those of dissolved N2 and Ar but can deviate as much as 20 percent between replicate samples because of varying extents of microbiological processes occurring in the sample bottles after collection and during storage prior to analysis.

Dissolved Helium-4

Water samples for analysis of dissolved helium were collected in 150-cc septum bottles without headspace, in a manner identical to the collection of samples for major dissolved gases. Samples were analyzed at the USGS Dissolved Gas Laboratory, Reston, Va., using a gas-chromatographic procedure (http://water.usgs.gov/lab/cfc/) that also determines the volume concentrations, σ, of dissolved hydrogen (H_2) and neon (Ne). The precisions of the analyses were 5–10, 10–20, and 10 percent for He, Ne, and H_2, respectively.

Chlorofluorocarbons

Water samples for CFC analysis were collected in 250-mL cap glass bottles with foil-lined caps (*http://water.usgs.gov/lab/cfc*). A closed path using copper tubing was established between the well or spring and the bottom of the bottle. The bottle was submersed in a bucket of source water and allowed to overflow several volumes before capping under water, without headspace. The caps were taped, and the bottles were returned to the USGS for analysis. Mass fractions of the CFCs, CFC-11 (trichlorofluoromethane, CFCl3), CFC-12 (dichlorodifluoromethane, CF2Cl2), and CFC-113, (trichlorotrifluoroethane, C2F3Cl3), were determined at the USGS Chlorofluorocarbon Laboratory, Reston, Va., using purge and trap gas chromatography with an electron-capture detector (Busenberg and Plummer, 1992; http://water.usgs.gov/lab/cfc/). The CFC mass fractions were calibrated to average air compositions measured at Niwot Ridge, Colo. (Climate Monitoring and Diagnostics Laboratory (CMDL) of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce (*http://www.cmdl.noaa.gov/*)). The detection limit for CFC-11 and CFC-12 mass fractions was near 0.3 picograms per kilogram of water (pg/kg) and approximately 1.0 pg/kg for CFC-113.

Tritium

Water samples for ^{3}H analysis were collected in 500-cc plastic bottles. The bottles were sealed with screw caps with conical liners. Approximately 10 cc of air space was left in the bottles during filling to accommodate expansion on warming. The samples were enriched electrolytically and analyzed by liquid scintillation counting in the low-level ^{3}H laboratory of the USGS, Menlo Park, Calif., following procedures modified from those described by Thatcher and others (1977).

Stable Hydrogen and Oxygen Isotopes

The relative stable isotope-amount ratio of hydrogen, δ^2H, is defined according to the relation

$$\delta^2\mathrm{H} = \frac{N\left(^2\mathrm{H}\right)_\mathrm{B} \big/ N\left(^1\mathrm{H}\right)_\mathrm{B} - N\left(^2\mathrm{H}\right)_\mathrm{B} \big/ N\left(^1\mathrm{H}\right)_\mathrm{B}}{N\left(^2\mathrm{H}\right)_\mathrm{VSMOW} \big/ N\left(^1\mathrm{H}\right)_\mathrm{VSMOW}}, \quad (1)$$

where $N(^2\mathrm{H})_\mathrm{B}/N(^1\mathrm{H})_\mathrm{B}$ and $N(^2\mathrm{H})_\mathrm{VSMOW}/N(^1\mathrm{H})_\mathrm{VSMOW}$ are the ratios of the isotopes ^{2}H and ^{1}H of hydrogen in unknown water B and the international measurement standard VSMOW. The hydrogen isotopic composition is reported on a scale such that the 10^3 δ^2H value of SLAP reference water is -428 exactly (Gonfiantini, 1978). For stable oxygen isotopes, δ^{18}O is defined according to the relation

$$\delta^{18}\mathrm{O} = \frac{N\left(^{18}\mathrm{O}\right)_\mathrm{B} \big/ N\left(^{16}\mathrm{O}\right)_\mathrm{B} - N\left(^{18}\mathrm{O}\right)_\mathrm{VSMOW} \big/ N\left(^{16}\mathrm{O}\right)_\mathrm{VSMOW}}{N\left(^{18}\mathrm{O}\right)_\mathrm{VSMOW} \big/ N\left(^{16}\mathrm{O}\right)_\mathrm{VSMOW}}, \quad (2)$$

where $N(^{18}\mathrm{O})_\mathrm{B}/N(^{16}\mathrm{O})_\mathrm{B}$ and $N(^{18}\mathrm{O})_\mathrm{VSMOW}/N(^{16}\mathrm{O})_\mathrm{VSMOW}$ are the ratios of the number of isotopes ^{18}O and ^{16}O of oxygen in unknown water B and the international measurement standard VSMOW. The oxygen isotopic composition is reported on a scale such that the 10^3 δ^{18}O value of SLAP reference water is -55.5 exactly (Gonfiantini, 1978).

Water samples for determination of the stable isotopic composition of oxygen and hydrogen were untreated and collected in 60-cc glass bottles with Polyseal liner caps. For determination of δ^2H values, water samples were analyzed using gaseous hydrogen equilibration (Coplen and others, 1991). The 2-σ precision of 10^3 δ^2H values is better than 2. For determination of δ^{18}O values, water samples are analyzed using the carbon dioxide-water equilibration technique of Epstein and Mayeda (1953). The 2-σ precision of 10^3 δ^{18}O values is better than 0.2.

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Appendix 5. Agricultural Water Use

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Appendix 5. Agricultural Water Use

A simplified surface energy balance (SSEB) method (Senay and others, 2007), described below, was used to estimate crop water use in the Kabul Basin. Global 1-degree reference ET (ETo), based on 6-hourly GDAS output, is calculated daily at USGS EROS on an operational basis (Verdin and Klaver, 2002; Senay and Verdin, 2003). The GDAS ETo uses the standard Penman-Monteith equation as outlined in the FAO publication by Allen and others (1998). The feasibility of using the GDAS ETo for such applications was recommended by Senay and Verdin (2005) after a comparison with station-based daily ETo showed encouraging results with r^2 values exceeding 0.9. Daily global reference ET values were available for all days between 2001 and 2006. For 2000, the daily reference ET values were not complete. For the missing time periods, the average reference ET from 2001 to 2005 was used.

Prior to using these data, a downscaling of the GDAS 1-degree results was performed to produce 10km GDAS reference ET data sets. The approach utilized the International Water Management Institute (IWMI) historical (1961–90) potential ET. The IWMI data set is originally a 16km spatial resolution that has been disaggregated to 10km. The downscaling technique utilized the 10km IWMI data to create a fractional relation, on a per-pixel basis, between each 10km IWMI pixel (x) and the corresponding 100km IWMI pixel (y) value (artificially created to match the 100km GDAS). This fractional relation could then be applied back to the 100km GDAS pixels to downscale these data to a spatial resolution of 10km:

$$x / y * \text{GDAS}$$

The result was a times series of daily fields of maximum potential ET at all locations (grid cells) in the study area, in units of millimeters per day.

The next step in the SSEB method uses remote sensing of land-surface properties to make estimates of actual ET fractions, which in most locations are less than the full potential amount defined by an ideal cover type (short grass) transpiring at a rate that fully meets atmospheric demand (ETo).

Image data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the NASA Terra satellite were used to measure land-surface temperature and vegetative cover. The MODIS instrument provides 36 spectral bands, including 16 in the thermal portion of the spectrum. Thermal surface measurements were collected from the MODIS 8-day Land Surface Temperature/Emissivity (LST/E) product (MOD11A2). The LST/E images provide per-pixel temperature and emissivity values at 1-km spatial resolution for the 8-day composite product. Temperatures are extracted in degrees Kelvin with a view-angle dependent algorithm applied to direct observations. This study utilized measurements of average daytime land-surface temperature for 8-day composite periods throughout the growing season. More than twenty 8-day periods beginning in early April through the end of October were processed for each year in the period 2001–2006.

MODIS Vegetation Index (VI) products use reflectance measures in the red (620–670 nm), near infrared (841–876 nm), and blue (459–479 nm) bands to provide spectral measures of vegetation vigor. The MODIS VI products include the standard normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI). Both indices are available at 250-m, 500-m, and 1-km spatial resolution. The primary difference between the two indices is that EVI uses blue reflectance to provide better sensitivity in high biomass regions. Because this study was concentrated on irrigated agriculture in an otherwise dry land environment, the standard 16-day NDVI product at 250-m resolution was used for this analysis. Images from the Landsat ETM+ and ASTER instruments were also used to define irrigated agricultural areas of interest in the Kabul Basin.

MODIS LST and NDVI data are distributed by the Land Processes Distributed Active Archive Center DAAC), located at the USGS EROS Center in Sioux Falls, S. Dak., as are the Landsat and ASTER images.

Full energy balance solutions with remote sensing (Allen and others, 2005; Bastiaanssen and others, 1998) assume that the temperature difference between the land surface and the air (near-surface temperature difference) varies linearly with land-surface temperature. This linear relation is used to estimate variations in the sensible heat flux. The technique is based on the use of two anchor pixels, *hot* and *cold*, representing dry and bare agricultural fields, in the first case, and wet, well-vegetated fields in the second. It assumes that the *hot* pixel experiences no latent heat, i.e., ET = 0.0, whereas the *cold* pixel achieves maximum potential ET. In the SSEB approach, this assumption is extended such that the latent heat flux (actual evapotranspiration) also varies linearly between the *hot* and *cold* pixels. While the *hot* pixel of a bare agricultural area experiences little ET, and the *cold* pixel of a well-watered irrigated field experiences maximum ET, the remaining pixels in the study area will experience ET in proportion to their land-surface temperature in the range defined by the *hot* and *cold* pixels (fig. 5-1).

The study focused on two major expanses of irrigation in the Kabul Basin, an extensive area north of Kabul in the Panjsher Valley and a narrower band of irrigation along the Kabul River south of the city. The northern area was sub-divided into two sections to minimize the effects of elevation differences on measurements of surface temperature. For each of the three areas, a polygon was defined around the irrigated fields by interpreting a combination of Landsat, ASTER, and MODIS images. The irrigated areas consist of both well-vegetated and sparsely vegetated areas, with some arid/semi-arid areas at the periphery.

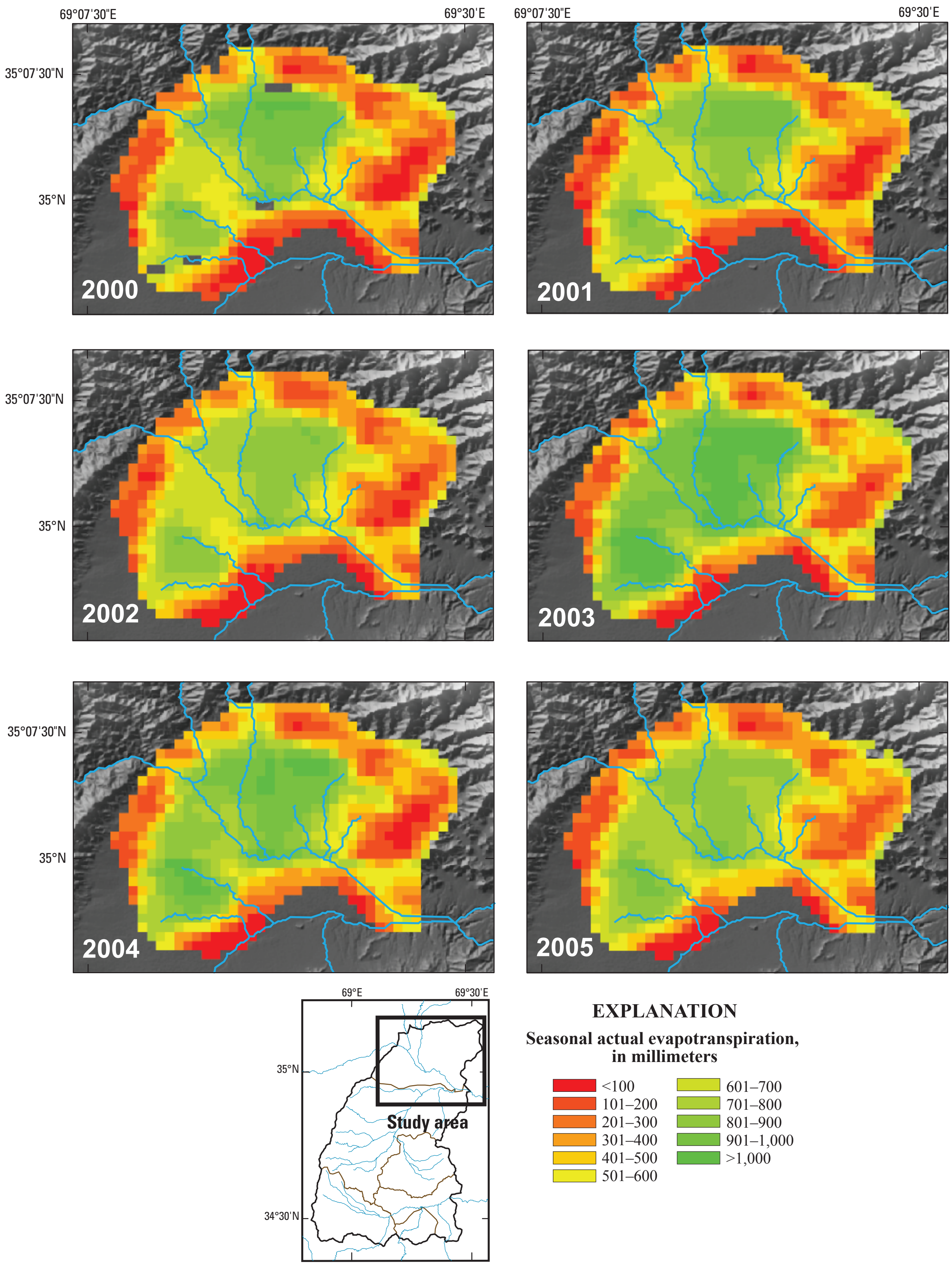

Figure 5-1. Estimates of seasonal actual evapotanspiration for irrigated lands above Shukhi streamgage on the Panjsher River.

Within each of the three areas, sets of three *hot* and three *cold* pixels were selected for each 8-day composite period for each growing season. An average of the three pixels was used to establish the reference *hot* and *cold* values throughout the study area. For each time period, cold pixels representing well-vegetated and well-watered crops were selected on the basis of a combination of low LST values and high MODIS NDVI values. Similarly, hot pixels, representing low-density vegetation and dry land, were identified by high LST values and very low NDVI values.

Values of land-surface temperature for each of the six pixels (three *hot*, three *cold*) were extracted using ArcGIS software. The resulting database files were imported into an Excel spreadsheet where average *hot* and *cold* pixel values were calculated.

The reference temperatures of the *hot* and *cold* pixels were used to calculate proportional fractions of ET on a per-pixel basis. The ET fraction (ETfrac) was calculated for each pixel by applying the following equation to each of the 8-day MODIS land-surface-temperature grids:

$$\mathrm{ETfrac} = \frac{\mathrm{TH} - \mathrm{Tx}}{\mathrm{TH} - \mathrm{TC}}, \tag{1}$$

where TH is the reference temperature from the *hot* pixels selected for a given scene; TC is the reference temperature of the *cold* pixels selected for that scene; and Tx is the land-surface temperature for any given pixel in the 8-day composite scene.

The ETfrac formula was applied to all the 8-day growing season composites for each year (fig. 5-2), resulting in a series of more than 25 images per season. The ETfrac images were used in conjunction with reference ET grids to calculate the per-pixel actual ET values for each scene. Daily reference ET images were averaged over 8-day periods to match the MODIS LST composite periods. The calculation of actual ET (ETact) was achieved using the following formula:

$$\mathrm{ETact} = \mathrm{ETfrac} * \mathrm{ETref}, \tag{2}$$

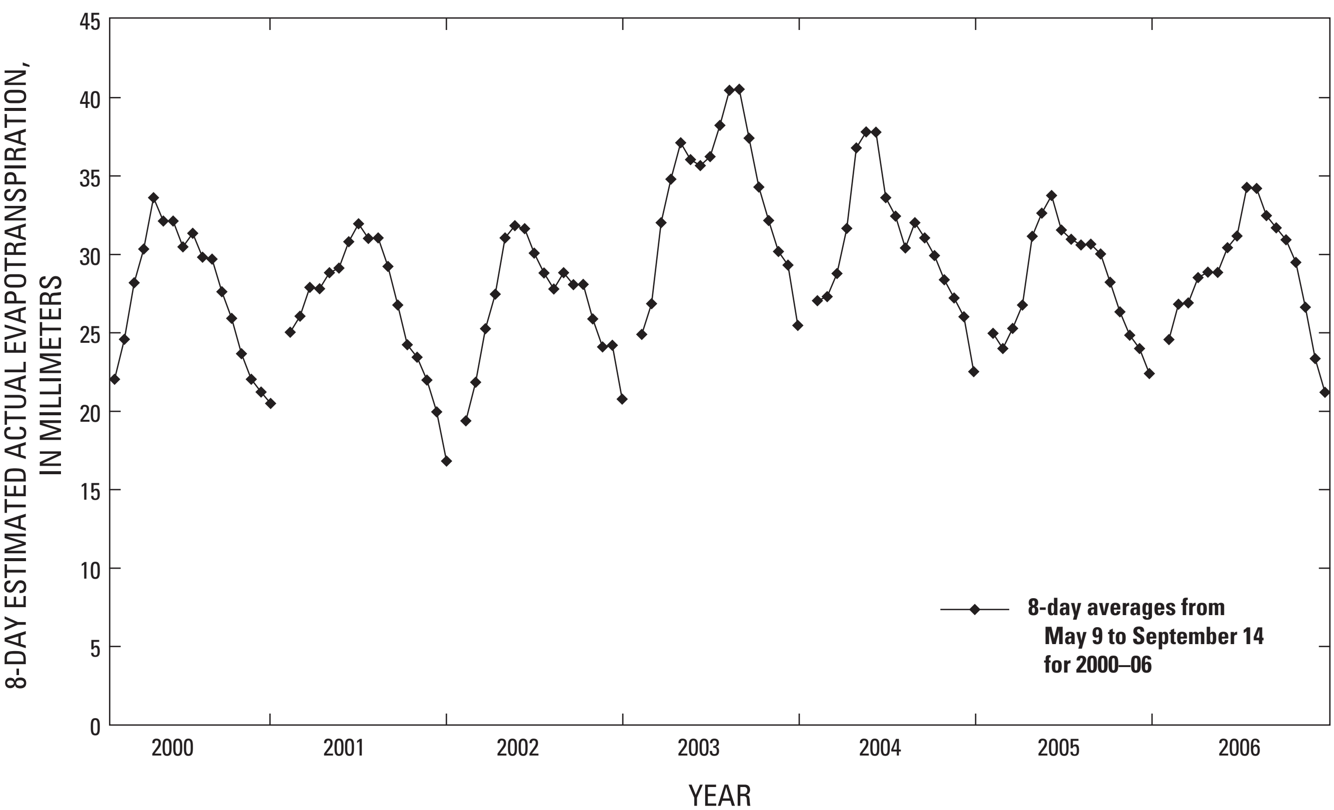

Figure 5-2. Seasonal traces of 8-day values of estimated actual evapotanspiration for irrigated lands above Shukhi streamgage on the Panjsher River.

This SSEB approach allowed for use of estimates of reference ET, at a coarse spatial resolution, to derive spatially distributed ET measurements on the basis of the variability of land-surface temperature at 1-kilometer resolution (fig. 7). Actual crop ET for the 7-year period, 2000–2006, was used to assess the quality of each growing season in the Kabul study areas. Polygons delineating irrigated crop areas were used with actual 1-km gridded ET values (fig. 7) to calculate spatially aggregated actual ET for each season, permitting preparation of seasonal traces of actual ET (fig. 5-2).

Water use was also estimated at small, scattered irrigated fields outside the three polygons modeled with the SSEB where, because of the relatively coarse spatial resolution of the 1-km MODIS thermal data, the SSEB could not be applied. In an effort to extrapolate findings for major irrigated areas to these smaller parcels, a regression equation was developed between seasonal ETa and MODIS seasonal maximum NDVI at a spatial resolution of 250 m. Only those pixels with seasonal maximum NDVI greater than or equal to 0.35 were used. To reduce data noise, the seasonal ETa values were averaged within NDVI classes at 0.05 increments from 0.35 to 0.8 using 2005 data from the Kabul 1 irrigation area (fig. 5-1). The resulting regression equation (seasonal ETa verses maximum NDVI) was reliable in that more than 90 percent of the spatial variability in seasonal ETa was explained by maximum NDVI. The regression equation was applied to the seasonal maximum NDVI data for each year to estimate seasonal ETa for small discontinuous areas of irrigation.

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Appendix 6. Conceptual Model Development

Contents

Table

Appendix 6. Conceptual Model Development

The Kabul Basin is in a "basin and range" setting, approximately 10 to 35 km wide and about 80 km long, where the valley is filled with quaternary and tertiary sediments and the ranges are composed of uplifted crystalline and sedimentary rocks (Bohannon and Turner, 2007). The generalized valley section (fig. 3) provides a general profile of the basin where Quaternary sediments are typically less than 80 m thick in the valley, the underlying tertiary (Neogene) sediments are as much as 1,000 m thick (Homilius, 1969), and the sediments are surrounded by primarily crystalline bedrock that forms the valley walls and basin boundaries.

The model was aligned with the primary axis of the basin where the lateral model boundary coincides with the major drainage divides forming the mountains that define the valley. The model was simulated with a horizontal cell size of 400 by 400 m in the row and column direction. The model was subdivided vertically into four layers (fig. 8) representing the major hydrogeologic units indicated in the generalized section shown in figure 3. The top-most model-cell elevations were interpreted from 30-m Digital Elevation Model (DEM) land-surface elevations averaged for each model cell. Model-layer thicknesses and extent address both hydrogeologic and numerical considerations and are discussed below. The model design used in this study was similar to that used by Pool and Dickinson (2007) for a regional groundwater flow simulation at the southwestern United States and northern Mexico border with similar geohydrologic characteristics.

Model layer 1 represents Quaternary and recent sediments in the valley-bottom, subbasin areas (fig. 8). To avoid dewatering model cells, layer 1 was not extended laterally up the hillsides where sediments may often be unsaturated. The thickness of layer 1 varies with location and was estimated using several sources of data. Drilling logs were obtained from records maintained by Afghanistan Geological Survey (AGS) (Amin Akbari, written commun., 2007) and (Eng. Hassan Safi, (Danish Committee for Aid to Afghan Refugees, written commun., 2007). A few hundred drilling records were concentrated in the developed areas of the city of Kabul, about 20 records were in the Shomali Plain near the center of the valley, and drilling records were fewer in the lateral margins of the model. Where available, drilling logs that indicated the depth to the top of Neogene (assumed to be the top of conglomerate sediments) were used to estimate the Neogene top elevation. In areas with no other information, recently dug or driven wells with no associated log information were used to indicate a minimum thickness of quaternary sediments. The depth to the Neogene in the model, which comprises the thickness of quaternary and recent sediments in model layer 1, was generally 30 to 60 m. Quaternary sediment thicknesses of just over 100 m were observed, and modeled, in some areas, primarily toward the centers of the subbasins.

Model layers 2 and 3 follow the elevation of the bottom of model layer 1, with the exception of hillsides, and each layer was 500 m thick (fig. 8). On hillsides, model layer 4 was the topmost model layer (fig. 8) and represented the mapped surficial geology (fig. 2), which was primarily bedrock. In the valley bottoms of the subbasin areas (fig. 1), Neogene sediments were assumed to be present beneath Quaternary and recent unconsolidated deposits (fig. 2). The Neogene and mapped consolidated rocks were extended through model layers 2 and 3 and were represented as an upper unit in layer 2 and a lower unit in layer 3. To roughly approximate basins that narrow with depth, the lateral extent of Neogene sediments in model layer 3 were assumed to be a few hundred meters closer to each basin center than in model layer 2 (fig. 8). Model layer 4 was designed to represent basal bedrock with a thickness of 1,000 m (fig. 3).

Boundary Conditions and Stresses

Boundary conditions and stresses were simulated using various MODFLOW-2000 model packages (Harbaugh and others, 2000) designed to represent components of the hydrologic system. River leakage and flow accumulation was simulated using the stream-flow routing (SFR1) package (Prudic and others, 2004). The rates of fluxes into or out of the model were estimated using results of various components of the investigation discussed in the report under Surface-Water Flow and Chemical and Isotopic Data. Stresses in the aquifer system include recharge, streamflow discharge, and domestic and agricultural water use. Recharge in the system includes direct infiltration of precipitation, leakage from the major rivers flowing through the basin (fig. 1), leakage from tributary perennial streams that drain adjacent upland areas (fig. 1), and lateral groundwater inflows from upland areas not drained by perennial streams (fig. 8). Recharge to the basin aquifers was from river leakage, leakage in irrigated areas, and from direct infiltration during the winter months.

Hydraulic Properties

The surficial and bedrock geology of the Kabul Basin was fairly well known and has recently been reinterpreted by Bohannon and Turner (2007) and Lindsay and others (2005). Geologic maps were used to assign zones of similar hydraulic properties in the conceptual model. The geology was grouped into eight major hydrogeologic zones (fig. 3) on the basis of general hydraulic conductivity and storage characteristics (table 6-1). The categories were Quaternary fan alluvium and colluvium (sand and gravel) (K1); river channel sediments (K2); loess (K3); unconsolidated conglomerates (K4); upper (K5) and lower (K6) Neogene sediments consisting of semi-consolidated fine-grained sediments and gravel; sedimentary rocks including sandstone, siltstone, limestone, and dolomite (K7); and all metamorphic and igneous rocks (K8). The hydraulic properties of the primary unconsolidated aquifer sediments in the Kabul Valley are generally high, on the order of 10s of meters per day. Hydraulic characteristics of the Quaternary and recent sediments (table 6-1) have been determined from aquifer tests (Böckh, 1971) and have been evaluated in other investigations (Houben and Tunnermeier, 2005; Niard, 2007).

The geohydrologic parameter categories used in the model were based on general hydraulic characteristics of sediments or rocks. The hydraulic properties of the secondary aquifers, for example various consolidated bedrocks, are generally orders of magnitude lower, than the unconsolidated (primary) aquifer sediments, and can be approximated for the purposes of a regional investigation from values reported in the literature (Freeze and Cherry, table 2.2, 1979) for similar materials. Although some zones contain geologic materials with distinctly different origin or nature, for the purpose of the conceptual model, they have relatively similar hydraulic properties and are grouped together (table 6-1). For example, sedimentary rocks and metamorphic and igneous rocks are grouped into two geohydrologic parameter zones, K7 and K8, respectively. These rocks contain numerous subunits with varying lithologic characteristics; however, the hydraulic conductivity and storage properties for these rocks are orders of magnitude lower than those for the other unconsolidated or partially consolidated rocks represented by the more permeable hydrogeologic zones (K1–K6). In regional groundwater flow systems, the simulated flow is typically less sensitive to low hydraulic-conductivity parameter zones than the higher hydraulic-conductivity parameter zones because much more groundwater is transmitted in the more permeable zones than in the less permeable zones.

Faults in the Kabul Basin are areas where the bedrock is likely to be highly fractured resulting in greater water-storage and transmitting capabilities. A number of fault systems, particularly the Sorubi-Konar fault system to the east and the Chaman-Paghman fault system to the west (Ruleman and others, 2007), are associated with the mountain ranges that define the Kabul Basin (fig. 3). Photolinear features (lineaments) in the Kabul Basin hillsides and ridges, observed by this investigation using LANDSAT imagery, were also considered to be possible fracture zones. Faults and lineaments were assumed to be fracture zones with hydraulic conductivity and porosity greater than the surrounding rock. Fracture zones were simulated in bedrock aquifers in model layers 2–4, by buffering mapped features by approximately 250 m, to ensure that they were represented by at least one model cell width were present, and were represented by a hydraulic conductivity and porosity an order of magnitude greater than the surrounding bulk rock properties (table 6-1).

Table 6-1. Model parameters and generalized hydraulic characteristics of sediment and rock aquifers in the Kabul Basin, Afghanistan.

[m/d, meters per day; – not known or available]

Sediment or rock unit	Hydraulic conductivity (m/d[1])	Geologic codes[2]	Conceptual model						
			Model layer(s)	Horizontal hydraulic conductivity (m/d)	Parameter code	Vertical hydraulic conductivity (m/d)	Parameter code	Porosity[3]
Fan alluvium and colluvium	–	Q_{34}ac	1	50	K1	5	K1v	0.28
River channel sediments	388.8	Q_4a	1	100	K2	10	K2v	0.3
Loess	34.56	Q_3loe	1	20	K3	2	K3v	0.28
Unconsolidated conglomerates	–	Q_3a	1	3	K4	0.3	K4v	0.28
Upper Neogene	8.64	N_2cgs	1,2	1	K5	0.1	K5v	0.1
Lower Neogene	–	N_2cgs	3	3	K6	0.3	K6v	0.1
Sedimentary rocks	–	all sedimentary rock codes	4	0.1	K7	0.1	K7v	0.01
Metamorphic and igneous rocks[4]	–	all metamorphic and igneous codes	4	0.01	K8	0.01	K8v	0.01

[1] Reported by Böckh (1971).

[2] Bohannon and Turner (2007) and Linsay and others (2005) shown on figures 3 and 8.

[3] Porosity used in flowpath analysis only.

[4] In areas of known or suspected fracturing or faulting the hydraulic conductivity was 0.1 m/d and porostiy was 0.05.

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Appendix 7. Geomorphology and Composition of Basin-Fill Sediments

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Figures

Appendix 7. Geomorphology and Composition of Basin-Fill Sediments

ASTER VNIR-SWIR reflectance and TIR decorrelation stretch imagery are shown in figures 2-1A and 2-1B, respectively. The TIR decorrelation stretch image (fig. 2-1B) broadly shows mixtures of rocks and basin sediments containing silicic, carbonate, and mafic minerals. For example, green-colored areas most abundant in carbonate minerals correspond with the Central Kabul and Paghman and Upper Kabul subbasin (fig. 2-1B). These subbasins are dominated by impervious cover and building materials in and around the city of Kabul, which are predominantly made from imported and (or) locally derived sources of limestone and marble building materials. Other notable areas of green-displayed carbonate-bearing minerals are alluvial fans and their limestone and marble source areas on the outer margins of the Dez Sabz subbasin, eastern parts of the Central Kabul subbasin, and southern margins of the Paghman and Upper Kabul subbasin (fig. 2-1B).

Orange and yellow areas may represent various mixtures of quartz-rich alluvium with either dry vegetation or carbonates in either alluvial or hardpan (caliche/calcrete) forms. These colors dominate the central portions of the Dez Sabz subbasin and the eastern half of the Central Kabul subbasin within our image coverage (fig. 2-1B). Surprisingly, cyan colors associated with weathered and ferric-oxidized ultramafic rock source areas to the northeast of the Kabul Basin study area (fig. 2-1B) do not appear in any of the basin alluvial sediments derived from these source areas. One possible explanation is that the rate of weathering of minerals characteristic of ultramafic rocks (e.g., olivine) exceeds the rate of erosion from these areas by catastrophic stream floods.

The most quartz-abundant areas appear bright red and correspond with the flood plains of major stream channels and eolian deposits characterized earlier in the paragraph describing photogeologic interpretation of the VNIR-SWIR imagery (fig. 2-1A). However, visual inspection of image spectra extracted from the latter areas in the corresponding TIR emissivity and VNIR-SWIR reflectance imagery suggests that these eolian deposits are not pure quartz sands but contain mixtures of clay, and perhaps even feldspar minerals. As a result, further analysis of the ASTER TIR and VNIR-SWIR data sets were conducted using several different band-ratios and relative band-depth images to highlight abundances of various minerals and mineral groups on the basis of their characteristic absorption features (Rowan and Mars, 2003; Rowan and others, 2005; Ninomiya and others, 2005; and Hewson and others, 2005), as well as matched-filter processing designed to partially unmix “target” foreground spectral endmembers from their composite “mixed” backgrounds (Harsanyi and Chang, 1994). The result of the latter processing yields images showing the relative abundances of each of the “relatively pure” spectral endmembers, which in this case were derived from the imagery and represent individual minerals, lithologic rock types, mineral-bearing soils, and other types of intimate mixtures of minerals.

Figure 7-1 summarizes the results of several band-ratio and relative absorption band-depth analyses, useful for showing abundances of different mineral types within the basin-fill sediments and surrounding bedrock source areas. In particular for TIR bands, these generally agree with the distribution of carbonate, mafic, and silicic minerals than the green, blue, and red components, respectively, of the decorrelation stretch image shown in figure 2-1B, though the former provides much clearer details on the spatial distribution of these minerals throughout the Kabul Basin. For example, carbonate minerals such as calcite and dolomite yield high brightness values in the ratio of TIR bands 13/14, for which green and (or) dry vegetation do not. Areas with the highest brightness values in this band-ratio appear white (fig. 7-1A) and correspond mainly to carbonate bedrock source areas (e.g., limestones and marbles). However, the red-colored areas suggest less-abundant amounts of carbonate minerals associated with either alluvium derived from these source areas, residual hardpans (e.g., calcrete/caliche) related to fluctuations in the groundwater table, or both. No attempts were made to mask out either the vegetation or the urban-built materials derived mainly from carbonate-rock source materials (fig. 7-1A), and stripping is due to coherent noise in these two bands, which was first noted in similar carbonate mineral mapping work done by Rowan and Mars (2003).

The Dez Sabz subbasin is dominated by carbonate minerals within basin-fill alluvium (fig. 7-1A), as suggested by the noticeable erosion and drainage pattern derived mainly from carbonate-abundant source rocks to the east. On the other hand, lack of carbonate bedrock source areas in the highlands to the west of the Kabul Basin (Bohannon and Turner, 2007) suggest that the Shomali subbasin and westernmost Paghman and Upper Kabul subbasin are dominated by carbonate minerals of the hardpan type rather than carbonate-rock alluvium (fig. 7-1A). Much of the carbonate mineral abundant areas of the easternmost Paghman and Upper Kabul, westernmost Central Kabul, and northernmost portions of the Logar subbasin appear to be related to impervious urban building materials made from carbonates (e.g., limestone/marble dimension stones, cement, and carbonate-rock dominated crushed stone and gravel), though carbonate bedrock sources do occur in areas to the south of these three subbasin (white-colored areas–fig. 7-1A). The areas with the least abundant amounts of carbonate minerals correspond with eolian deposits, which dominate the northeastern portion of the Shomali subbasin, and much of the surrounding bedrock source areas that contain mostly crystalline and siliciclastic bedrock types (fig. 7-1A). In sum, the eastern half of the Kabul Basin appears to be dominated by alluvial carbonate sources, and the western half of the basin appears to be dominated by hardpan carbonate sources (fig. 7-1B), though both types are likely to occur together in varying proportions throughout all of the five subbasins.

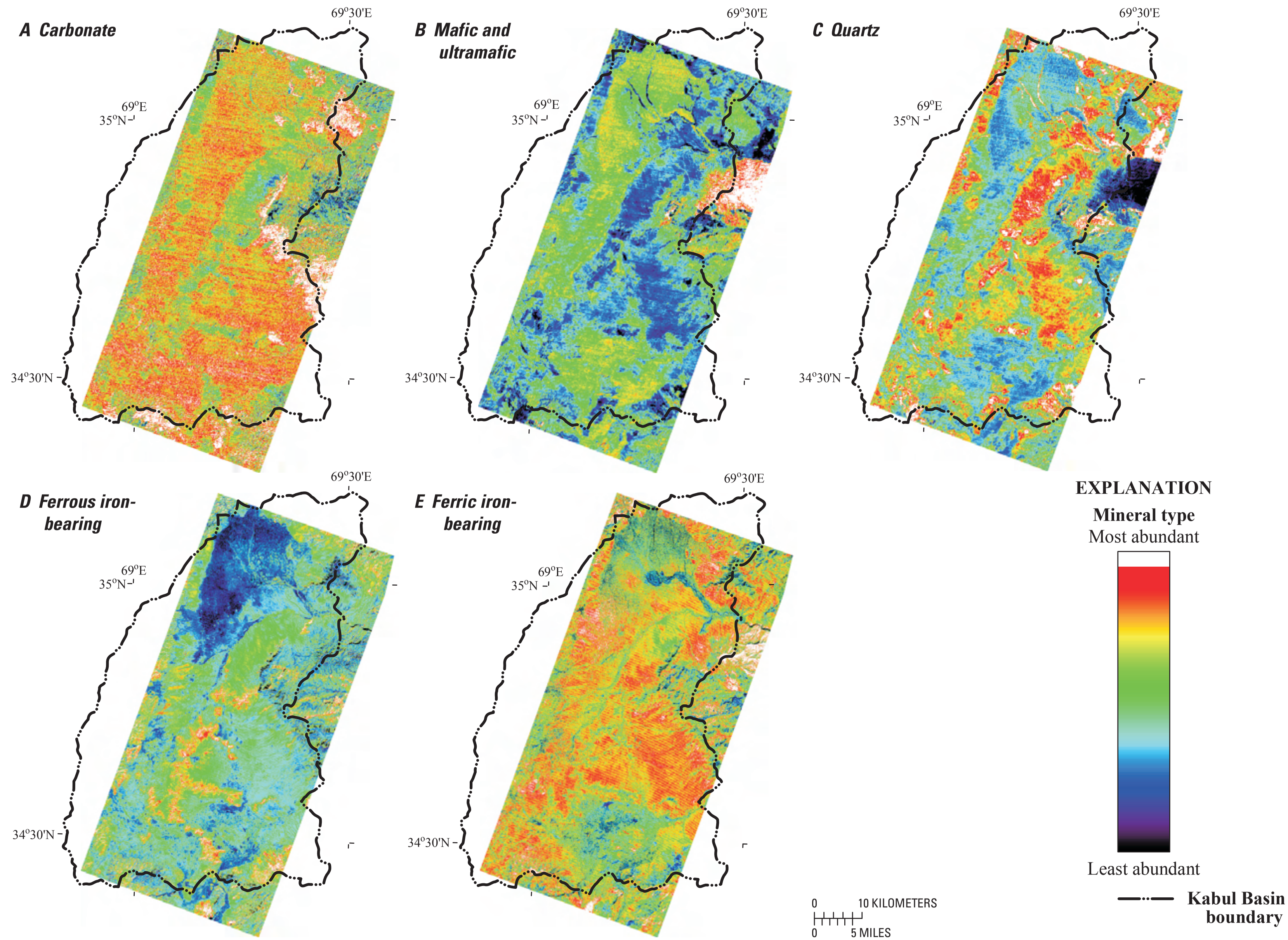

Figure 7-1. ASTER analysis of relative abundance of mineral groups containing (A) carbonate, (B) mafic and ultramafic minerals, (C) quartz, (D) ferrous iron, and (E) ferric iron in the Kabul Basin, Afghanistan. (This figure is the same as figure 11 on page 24 in the report).

Figure 7-1B shows a relative band-depth (RBD) image of TIR bands (12+14)/(13*2) (also referred to as RBD13–Rowan and others, 2005), which highlights the distribution of rocks and sediments containing abundant mafic minerals such as olivine, pyroxene and (or) amphiboles. Mafic mineral areas appear to be lacking throughout much of the Kabul Basin, with areas corresponding to the ultramafic complex northeast of the basin described previously, containing the most abundant levels of these minerals (white- and red-colored areas, fig. 7-1B). Notably, this large area appears distinctly cyan-colored in the decorrelation stretch image (fig. 2-1B). The fact that basin-fill sediments lack the spectral signatures of mafic and ultramafic rock source areas in the surrounding mountains suggest that these minerals do not survive the weathering process and are instead easily converted to other mineral phases such as ferric-iron, clays, and silica. Areas with yellow-colored abundant levels are mostly the result of noise between band 13 and neighboring bands 12 and 14, for areas covered with dense vegetation that were not masked (fig. 7-1B).

The quartz abundance map (fig. 7-1C) is based on the ratio of TIR bands 13/12 and yields a spatial distribution pattern that mimicks the inverse of that of the mafic rock abundance map (fig. 7-1B). This is not surprising because fresh mafic and ultramafic rocks contain little or no quartz, other than residual silica derived from weathering (Kahle and others, 1988). The areas most abundant in quartz appear white-colored (fig. 7-1C) and correspond with Pliocene clastic and Quaternary detrital sediments (mostly sandstone, gravel and loess deposits) northeast of the modern Kabul basin (Bohannon and Turner, 2007). The distribution of quartz in modern-day Kabul basin-fill sediments (red-colored areas–fig. 7-1C) are indicative of the degree of weathering and residual-soil development on alluvial fans and pediments, as well as the amount of alluvial and eolian transport from quartz-rich rocks such as granites, grano-diorites, sandstones, conglomerates, and quartzites surrounding the basin. The Dez Sabz subbasin and the westernmost areas of the Shomali subbasin (fig. 7-1C) contain abundant quartz that appears to be first type (i.e., residual quartz derived from in-situ chemical weathering of alluvial-fan material). This is based on the bedrock geology of the respective source areas, which are predominantly mafic gneisses to the west of the Shomali basin and mafic gneisses and carbonates surrounding the Dez Sabz (Bohannon and Turner, 2007). The northeastern portion of the Shomali subbasin is dominated by quartz of the second type that appears to be eolian in origin and mixed with other minerals as discussed earlier (fig. 7-1C).

The distribution of ferrous- and ferric-iron bearing minerals are shown in figures 7-1D and 11E, respectively. The distribution of ferrous-iron bearing minerals (fig. 7-1D) is based on the ratio sum of ASTER VNIR-SWIR bands (1/2) + (5/3), which resolves the slope of major ferrous absorption features near 1.0 µm, displayed by mafic minerals such as olivine, pyroxene, amphibole, serpentine, biotite, and chlorite (Rowan and others, 2005). The distribution of ferric iron bearing minerals, such as hematite and goethite, were resolved using the ratio of bands 2/1 (fig. 7-1E). With the exception of a few areas, perhaps exposing fresh and least-weathered rocks, most of the bedrock source areas containing quartz-poor ultramafic rocks (fig. 7-1C) appear to contain more abundant ferric-iron minerals (white areas, fig. 7-1E) than ferrous-iron minerals (red and white areas, fig. 7-1D), most likely the result of extensive weathering over time. Other areas displaying abundant ferrous-iron minerals correspond to bedrock and youngest alluvial fan and talus material derived from biotite- and amphibole-bearing gneiss source areas surrounding the basin (Bohannon and Turner, 2007). Notably, the basin sediments are depleted in ferrous-iron minerals (fig. 7-1D), because of their higher susceptibility to weathering as noted previously. However, transported and residual forms of ferric-iron (i.e., alluvial and hardpan) appear to dominate all of the subbasin of the Kabul Basin (red-colored areas, fig. 7-1E), except for the city of Kabul and surrounding suburbs that are dominated by urban/impervious land-cover materials, typically derived from carbonate rock sources. Indeed, many areas containing abundant ferric-iron, perhaps in hardpan form such as ferricrete, also contains abundant carbonate minerals in the form of calcrete (compare fig. 7-1A with fig. 7-1E).

Other stable and (or) residual mineral phases with greater degrees of resistance to chemical weathering, such as clay and mica minerals, were mapped using spectral endmembers identified within the VNIR-SWIR reflectance, followed by matched-filter processing as described earlier. In this case, VNIR-SWIR spectral endmembers representing pixels dominated by clay- and mica-minerals and TIR spectral endmembers representing feldspar-minerals and (or) intermediate-composition volcanic rocks were chosen on the basis of a principal component analysis and pixel purity index analysis described by Green and others (1988) and Boardman and others (1995), respectively. TIR spectral endmembers representing feldspar-bearing deposits, were mapped using the spectral angle mapper (SAM) algorithm described by Kruse and others (1993). SAM outputs images showing the similarity in spectral shape between image spectra and reference spectral endmembers, which can be used as a measure of abundance of any particular spectral endmember from pixel to pixel.

The area containing the most abundant distribution of feldspar minerals on the basis of the TIR emissivity data is the eolian deposits within the northeastern portion of the Shomali subbasin (fig. 7-2A). Notably, clay- and feldspar-rich rocks both exhibit lower band 11 emissivity and higher band 12 emissivity than rocks and sediments containing higher proportions of quartz (Rowan and others, 2005). However, in this case, VNIR-SWIR analysis suggests that clay abundances are relatively low throughout much of these eolian deposits as compared to other parts of the Kabul Basin dominated by alluvial basin-fill sediments (yellow- and green-colored smectite abundant levels, fig. 7-2B), which suggests that they are comprised mostly of mixtures of quartz (fig. 7-1C), feldspars (fig. 7-2A), and ferric-iron (fig. 7-1E) with only minor amounts of clays (fig. 7-2B) and carbonates (fig. 7-1A). Other notable areas of high feldspar abundances include felsic-gneiss bedrock areas within exposed metamorphic terraines such as the central highland areas within the Kabul Basin and the younger (least weathered) alluvial fans and felsic-gneiss bedrock source areas to the west (fig. 12A; Bohannon and Turner, 2007).

Analysis of VNIR-SWIR image spectra throughout the Kabul Basin and surrounding areas suggests that aluminous-clays with prominent 2.2 µm absorptions are widespread and ubitiquous throughout the basin-fill sediments and bedrock source areas. However, the Dez Sabz subbasin appears to contain the most abundant amounts of smectite clays such as montmorillonite (white-colored areas, fig. 7-2B). Smectites are shrink-swell clays that tend to form in areas of poor-drainage, commonly resulting in impermeable soils and groundwater aquitards in buried sediments. Smectite clays also appear abundant in the eastern portions of the Central Kabul subbasin, western portions of the Paghman and Upper Kabul subbasin, and southernmost portions of the Shomali subbasin (fig. 7-2B). These areas all correspond with areas that appear bright white in the false-colored composite of ASTER bands 6, 3 and 1 shown in figure 7-1B.

Biotite- and (or) chlorite-bearing areas (white- and red-colored areas, fig. 7-2C) generally correspond well with areas containing abundant ferrous-iron minerals based on band-ratios (red- and white-colored areas, fig. 7-1D), though the former shows better detail and resolves talus deposits associated with the main bedrock outcrop source areas. Notably, biotite-rich metamorphic rocks are exposed in the bedrock highland areas of the central parts of the Kabul Basin (Bohannon and Turner, 2007). Chlorite is a major constituent of serpentinized mafic- and ultramafic rocks and can also occur as a weathering product of biotite. Both minerals have broadly similar spectral shapes, but chlorite has a considerably stronger Mg-OH absorption feature near 2.33 µm and a stronger ferrous iron (Fe^{2+}) slope near 1.00 µm (Rowan and others, 2005). Chlorite of the first type (serpentization) is most likely responsible for the white-colored abundant levels (fig. 7-2C) covering least-weathered parts of the ophiolite deposit exposed to the northeast of the Kabul Basin. The presence of smectite absorption features in biotite and (or) chlorite-rich areas suggest that these rocks may have undergone considerable weathering, even in areas closest to the bedrock source where we expect the freshest exposures to occur. Except for talus deposits adjacent to their source bedrock outcrops, the basin-fill deposits appear to be depleted in chlorite and (or) biotite (fig. 7-2C), which agrees with the corresponding ferrous-iron ratio abundance maps (fig. 7-1D).

Illite and muscovite are common constituents of K-rich rocks and sediments. Illite is a clay mineral, typically of detrital origin, which is commonly derived from the weathering of mica-rich rocks. Both minerals have similar and nearly indistinguishable absorption features in hyperspectral data (Zhang and others, 2001), which become even less distinguishable when resampled to the SWIR multispectral resolution of ASTER (Rowan and others, 2005). Although the most common varieties of illite and muscovite share prominent 2.22 µm absorption features with smectite, they can be distinguished on the basis of secondary absorption features near 2.33 µm (Rowan and others, 2005). The areas containing the most abundant amounts of illite and (or) muscovite (white-colored areas, fig. 7-2D) correspond with many of the bedrock areas containing the most abundant quartz (white-colored areas, fig. 7-1C). These areas are mapped as Proterozoic mica-bearing gneisses and schists, Pliocene-age clastic sedimentary rocks, and Quaternary-age shingly and detrital sediments (Bohannon and Turner, 2007). In fact, prominent bedding-like structure displayed in several of these white-colored bedrock areas (fig. 7-2D) suggest that they may be highlighting foliation structure within mica-schist members of these Proterozoic rocks. Smaller, circular-shaped bedrock areas containing abundant illite and (or) muscovite could be related to unmapped intrusive rocks and (or) associated hydrothermal alteration. With the possible exception of the northwestern portion of the Shomali subbasin, much of the basin-fill sediments of the Kabul Basin appear to contain relatively lower abundances of illite and (or) muscovite (fig. 7-2D). Dry vegetation and carbonates share an overlapping absorption feature with illite at 2.33 µm, such that mixtures of smectite with either or both carbonate and dry vegetation material can resemble illite and (or) muscovite. Therefore, because the northwestern parts of the Shomali subbasin contain abundant carbonate (figs. 7-1A and 7-2E) as well as extensively cultivated vegetation (fig. 2-1B), these areas with apparently high illite and (or) muscovite abundance levels could be the result of abundant smectite rather than illite or muscovite (figs. 7-2B and D).

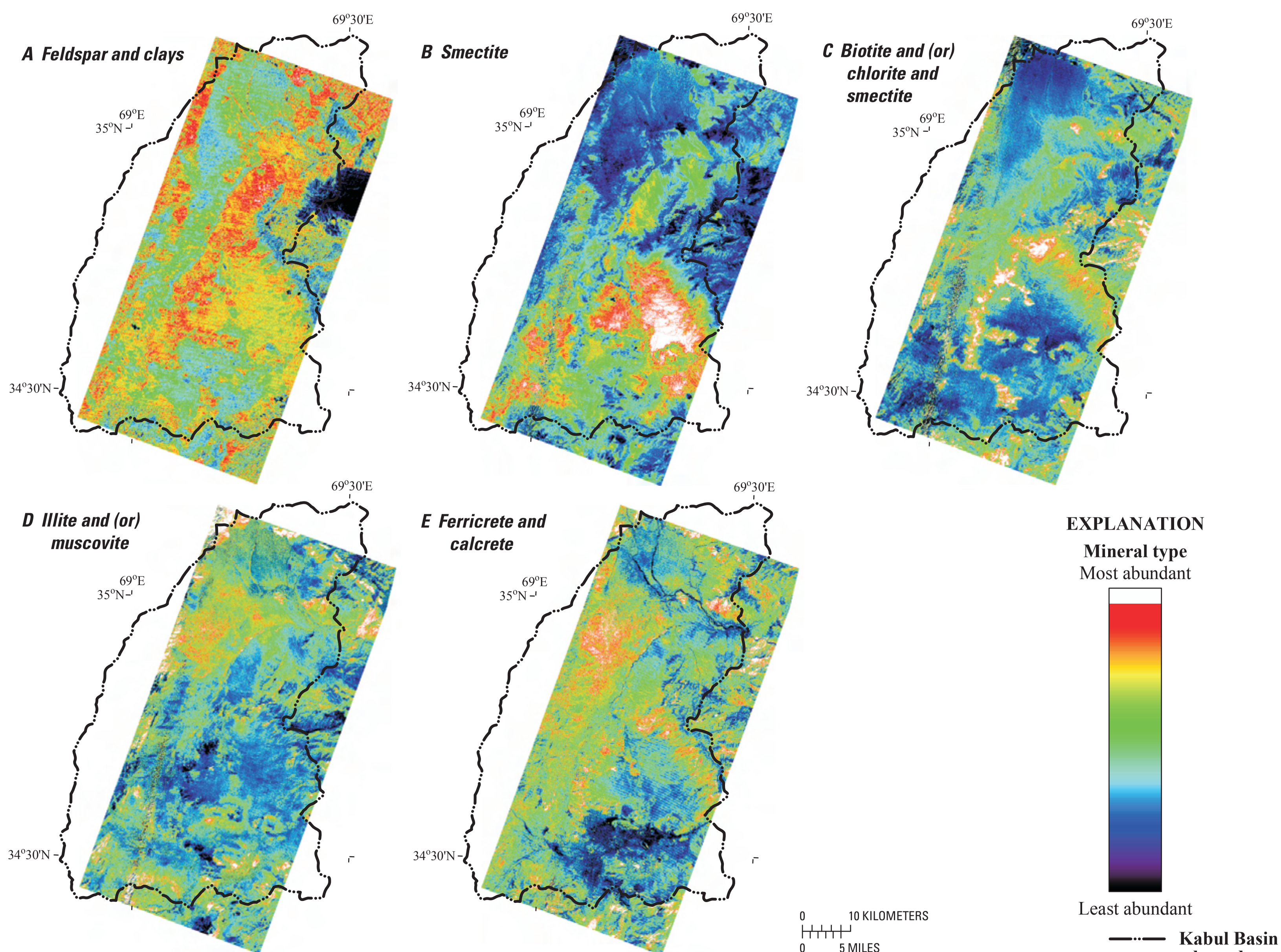

Figure 7-2. ASTER analysis of relative abundance of mineral groups containing (A) feldspar and clays, (B) smectite clays, (C) biotite and (or) chlorite and smectite, (D) illite and (or) muscovite, and (E) ferricrete and calcrete minerals in the Kabul Basin, Afghanistan. (This figure is the same as figure 12 on page 25 in the report)

With the exception of the built-up areas in and around the city of Kabul, basin-fill deposits of the Kabul Basin contain abundant carbonate minerals (red-colored areas, fig. 7-1A) and ferric-iron minerals (red-colored areas, fig. 7-1E) as noted earlier using TIR and VNIR-SWIR band-ratios. Spectral matched-filter processing suggests that the areas containing the most abundant ferricrete and calcrete deposits, of perhaps hardpan origin, are the northwestern portion of the Shomali subbasin, several of the alluvial fans derived from middle Triassic carbonate-bearing bedrock source areas to the northeast of the Dez Sabz subbasin, and sizeable patches of the Logar subbasin that are clearly distinguishable from bedrock (fig. 7-2E). However, the areas displaying the highest levels of abundance (white-colored areas, fig. 7-2E) of this hardpan (or alluvial?) mixture lay outside of the Kabul Basin. Several of these are limestone bedrock exposures of Cambrian-age and mineralized areas along the Herat suture-zone to the northwest of the basin (Bohannon and Turner, 2007). Other notable areas are within the ophiolite complex northeast of the Kabul Basin, which exposes serpentinized and weathered ultramafic rocks containing abundant chlorite and ferric-iron minerals (figs. 7-2C and 7-1E, respectively). Because chlorite share a prominent absorption feature at 2.33 µm with calcite, the two minerals can easily be confused and mis-identified using solely ASTER VNIR-SWIR data without the additional information provided using the ASTER TIR bands (Dalton and others, 2004; Rowan and others, 2005).

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Appendix 8. Surface-Water Analysis

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Tables

Appendix 8. Surface-Water Analysis

The probabilities of occurrence of annual high discharges are presented in table 8-1 for the 12 streamgages. Probability of occurrence is an estimate of the likelihood that a particular discharge in a stream will be equaled or exceeded in a given year. The probability of occurrence of a high flow is called the exceedance probability. For example, the maximum instantaneous discharge for the 0.20 exceedance probability is listed as 56.2 m^3/s for Kabul River at Tang-i-Saidan, then a 20 percent chance exists that a discharge equal to or greater than 56.2 m^3/s will occur once during the year. Recurrence interval is another way of expressing annual probability and is the reciprocal of probability of occurrence. For example, the recurrence interval for an exceedance probability of 0.20 is 5 years (1 divided by 0.20). For a long discharge record, the annual maximum discharge can be expected to equal or exceed that discharge on average once every 5 years.

The maximum instantaneous discharge and the maximum mean discharge for 3, 7, 15, and 30 consecutive-day periods for selected exceedance probabilities and recurrence intervals are listed in table 8-1. Values for the maximum mean discharges for 3, 7, 15, and 30 consecutive-day periods are computed from the annual high mean values of the corresponding periods. The computations are based on the log-Pearson Type III distribution using values obtained for the water year. The difference in percent between the maximum instantaneous discharge and a maximum mean discharge for a "n" consecutive-day period can be used as an indicator of the flashiness of a flood. As an example, the mean discharge for a 3 consecutive-day period for a recurrence interval of 25 years for streamgages Qargha River above Qargha Reservior and Paghman River at Pul-i-Sokhta are 72 and 77 percent, respectively; the recurrence intervals for the rest of the streamgages are from 11 to 32 percent. Therefore, the high flows are much shorter duration (flashier) at the streamgages Qargha River above Qargha Reservior and Paghman River at Pul-i-Sokhta than at the other streamgages.

The annual peak discharges for each of the 12 streamgages are listed in table 8-2. The recurrence intervals for the peak discharge for the period of record are 10 years for streamgage at Shatul River at Gulbahar; 10–25 years for streamgages Qargha River above Qargha Reservoir, Qargha River below Qargha Reservoir, Paghman River at Pul-i-Sokhta, Logar River at Sang-i-Naweshta, Kabul River at Tang-i-Gharu, Panjsher River at Gulbahar, and Panjsher River at Shukhi; 25 years for streamgages Chakari River at Band-i-Amir Ghazi, Kabul River at Tang-i-Saidan, and Ghorband River at Pul-i-Ashawa; and 50 years for streamgage Salang River at Bagh-i-Lala. The instantaneous peak discharge of 192 m^3/s was on April 28, 1967, for streamgage Kabul River at Tang-i-Gharu, and the instantaneous peak discharge of 750 m^3/s was on June 12, 1967, for the streamgage Panjsher River at Shukhi.

The annual low discharge in any given year is sensitive to natural-channel processes, such as evapotranspiration and groundwater gains and losses, and human-induced hydrologic modifications, such as the operation of many small water-storage reservoirs; the effects of surface-water withdrawal for agricultural, municipal, and industrial use; and the effects of return flow to the river. The probabilities of occurrence of annual low discharges are presented in table 8-3 for the 12 streamgages. Probability of occurrence is an estimate of the likelihood that a particular discharge in a stream will be equaled or exceeded in 1 year or, in the case of low flows, the likelihood that the discharge will not be equaled or exceeded during the year. The probability of occurrence of low flow is called the nonexceedance probability. The table of probability of occurrence of annual low discharges for each streamgage lists the minimum mean discharge for 1, 3, 7, 14, 30, and 60 consecutive-day periods for selected nonexceedance probabilities and recurrence intervals. Values for the minimum mean discharges are computed from the annual low discharge values of the corresponding periods using the log-Pearson Type III distribution. Probabilities of annual low discharges are computed using values for the climatic year (April 1 through March 31).

Table 8-1. Probability of occurrence of annual high discharge for the period of record at streamflow-gaging stations in the Kabul study area, Afghanistan.

[m^3/s, cubic meters per second]

Exceedance probability	Recurrence interval (years)	Maximum instantaneous (m^3/s)	Maximum mean discharge (m^3/s)			
			3-day period	7-day period	15-day period	30-day period
Kabul River at Tangi Saidan						
0.99	1.01	7.4	5.40	4.08	3.44	2.73
0.95	1.05	12.5	8.40	6.93	6.04	4.94
0.90	1.11	16.3	10.60	9.08	8.01	6.63
0.80	1.25	21.9	14.10	12.40	11.10	9.29
0.50	2	36.3	24.30	22.00	19.70	16.70
0.20	5	56.2	41.70	37.10	32.80	28.00
0.10	10	68.7	55.20	48.00	41.90	35.70
0.04	25	83.4	74.40	62.30	53.50	45.30
0.02	50	93.6	90.20	73.30	62.00	52.30
0.01	100	103.0	107.00	84.40	70.40	59.10
Qargha River above Qargha Reservoir						
0.99	1.01	1.7	1.51	1.31	1.03	0.90
0.95	1.05	2.3	1.94	1.65	1.33	1.13
0.90	1.11	2.7	2.20	1.87	1.52	1.27
0.80	1.25	3.2	2.54	2.17	1.79	1.48
0.50	2	4.2	3.32	2.88	2.47	2.00
0.20	5	5.3	4.26	3.83	3.43	2.73
0.10	10	5.9	4.81	4.44	4.08	3.23
0.04	25	6.6	5.45	5.20	4.93	3.89
0.02	50	7.0	5.89	5.76	5.57	4.39
0.01	100	7.3	6.30	6.32	6.23	4.90
Qargha River below Qargha Reservoir						
0.99	1.01	0.4	0.35	0.32	0.29	0.25
0.95	1.05	0.4	0.37	0.34	0.32	0.28
0.90	1.11	0.4	0.38	0.36	0.34	0.30
0.80	1.25	0.5	0.42	0.40	0.37	0.33
0.50	2	0.7	0.54	0.53	0.49	0.43
0.20	5	1.3	0.87	0.82	0.72	0.62
0.10	10	2.1	1.22	1.11	0.92	0.79
0.04	25	4.0	1.87	1.62	1.26	1.05
0.02	50	6.5	2.59	2.14	1.58	1.28
0.01	100	10.6	3.56	2.82	1.97	1.56

Table 8-1. Probability of occurrence of annual high discharge for the period of record at streamflow-gaging stations in the Kabul study area, Afghanistan.—Continued

[m^3/s, cubic meters per second]

Exceedance probability	Recurrence interval (years)	Maximum instantaneous (m^3/s)	Maximum mean discharge (m^3/s)			
			3-day period	7-day period	15-day period	30-day period
Paghman River at Pul-i-Sokhta						
0.99	1.01	1.8	0.89	0.63	0.45	0.39
0.95	1.05	3.4	1.70	1.25	0.96	0.79
0.90	1.11	4.7	2.37	1.79	1.41	1.14
0.80	1.25	7.2	3.50	2.71	2.20	1.73
0.50	2	16.0	7.13	5.81	4.78	3.65
0.20	5	35.6	13.9	11.9	9.57	7.18
0.10	10	54.3	19.4	17.0	13.3	9.95
0.04	25	85.0	27.2	24.5	18.5	13.8
0.02	50	114.0	33.7	30.8	22.7	16.9
0.01	100	148.0	40.6	37.6	27.0	20.1
Logar River at Sang-i-Naweshta						
0.99	1.01	16.1	13.0	13.3	12.3	11.2
0.95	1.05	22.0	18.0	17.3	15.5	13.7
0.90	1.11	26.0	21.4	20.0	17.8	15.5
0.80	1.25	31.7	26.3	24.0	21.0	18.0
0.50	2	46.0	39.1	34.8	29.9	25.0
0.20	5	66.4	48.0	42.4	36.4	30.0
0.10	10	80.3	58.2	51.4	44.1	36.1
0.04	25	98.0	71.6	63.8	54.7	44.4
0.02	50	111.0	89.4	80.8	69.7	56.4
0.01	100	125.0	103.0	94.5	82.1	66.2
Chakari River at Band-i-Amir Ghazi						
0.99	1.01	0.3	0.27	0.27	0.25	0.24
0.95	1.05	0.4	0.39	0.39	0.36	0.34
0.90	1.11	0.5	0.47	0.47	0.44	0.42
0.80	1.25	0.7	0.59	0.59	0.55	0.52
0.50	2	1	0.9	0.89	0.85	0.78
0.20	5	1.4	1.34	1.32	1.27	1.14
0.10	10	1.7	1.64	1.62	1.55	1.38
0.04	25	2	2.02	1.99	1.92	1.67
0.02	50	2.2	2.31	2.27	2.19	1.89
0.01	100	2.4	2.59	2.55	2.46	2.1

Table 8-1. Probability of occurrence of annual high discharge for the period of record at streamflow-gaging stations in the Kabul study area, Afghanistan.—Continued

[m^3/s, cubic meters per second]

Exceedance probability	Recurrence interval (years)	Maximum instantaneous (m^3/s)	Maximum mean discharge (m^3/s)			
			3-day period	7-day period	15-day period	30-day period
Kabul River at Tangi-Gharu						
0.99	1.01	27.4	16.2	15.0	12.6	11.6
0.95	1.05	41.5	26.4	23.9	20.4	18.2
0.90	1.11	51.0	33.8	30.4	26.1	22.9
0.80	1.25	64.8	45.1	40.3	35.0	30.1
0.50	2	98.3	75.4	67.9	59.6	50.1
0.20	5	142.0	121.0	111.0	97.9	81.6
0.10	10	169.0	152.0	142.0	125.0	104.0
0.04	25	201.0	192.0	184.0	161.0	135.0
0.02	50	223.0	221.0	215.0	189.0	158.0
0.01	100	244.0	250.0	247.0	217.0	183.0
Panjsher River at Gulbahar						
0.99	1.01	209	179	166	146	125
0.95	1.05	255	209	193	172	152
0.90	1.11	282	227	210	188	168
0.80	1.25	318	250	232	209	189
0.50	2	394	300	281	257	234
0.20	5	483	360	343	317	286
0.10	10	534	395	381	353	316
0.04	25	592	436	427	398	349
0.02	50	631	465	460	429	372
0.01	100	668	492	492	460	393
Shatul River at Gulbahar						
0.99	1.01	16.1	9.47	8.86	8.20	7.06
0.95	1.05	19.2	11.90	11.20	10.30	9.10
0.90	1.11	21.2	13.40	12.60	11.70	10.40
0.80	1.25	23.7	15.40	14.50	13.40	12.10
0.50	2	29.5	19.80	18.60	17.50	15.90
0.20	5	36.7	25.00	23.60	22.40	20.60
0.10	10	41.1	28.00	26.60	25.40	23.40
0.04	25	46.4	31.50	30.00	28.90	26.70
0.02	50	50.2	33.90	32.40	31.30	28.90
0.01	100	53.9	36.10	34.60	33.70	31.00

Table 8-1. Probability of occurrence of annual high discharge for the period of record at streamgages in the Kabul study area, Afghanistan.—Continued

[m³/s, cubic meters per second]

Exceedance probability	Recurrence interval (years)	Maximum instantaneous (m³/s)	Maximum mean discharge (m³/s)			
			3-day period	7-day period	15-day period	30-day period
Ghorband River at Pul-i-Ashawa						
0.99	1.01	55.0	48.0	44.4	41.5	38.3
0.95	1.05	67.0	57.1	53.0	49.6	45.7
0.90	1.11	74.2	62.6	58.3	54.6	50.3
0.80	1.25	83.7	70.0	65.5	61.2	56.4
0.50	2	104.0	86.8	81.8	76.3	70.3
0.20	5	129.0	107.0	102.0	94.9	87.7
0.10	10	143.0	120.0	115.0	106.0	98.4
0.04	25	159.0	135.0	131.0	120.0	111.0
0.02	50	170.0	146.0	142.0	130.0	120.0
0.01	100	180.0	157.0	152.0	139.0	130.0
Salang River at Bagh-i-Lala						
0.99	1.01	18.9	11.9	10.7	10.1	9.79
0.95	1.05	26.8	17.7	16.7	16.0	15.1
0.90	1.11	32.0	21.6	20.6	19.7	18.5
0.80	1.25	39.4	27.1	26.0	24.7	22.9
0.50	2	57.2	40.1	37.7	34.8	31.8
0.20	5	80.6	56.2	50.3	44.4	40.2
0.10	10	95.2	65.8	56.7	48.6	44.0
0.04	25	113.0	76.7	63.1	52.4	47.3
0.02	50	125.0	84.1	66.9	54.3	49.1
0.01	100	137.0	90.9	70.1	55.8	50.4
Panjsher River at Shukhi						
0.99	1.01	318	248	227	200	178
0.95	1.05	375	296	273	242	215
0.90	1.11	408	325	300	267	238
0.80	1.25	453	362	336	300	268
0.50	2	548	440	412	374	338
0.20	5	659	528	499	462	424
0.10	10	724	578	549	514	477
0.04	25	798	633	605	575	541
0.02	50	849	671	644	618	586
0.01	100	897	705	679	658	630

Table 8-2. Annual peak discharge for streamgages in the Kabul study area for the period of record.

[m^3/s, cubic meters per second]

Water year	Date	Peak discharge (m^3/s)	Water year	Date	Peak discharge (m^3/s)
		Kabul River at Tangi Saidan			
1962	April 20, 1962	25.7	1972	April 28, 1972	58.2
1963	May 4, 1963	30.7	1973	April 11, 1973	47.0
1964	April 12, 1964	34.3	1974	April 7, 1974	18.5
1965	April 23, 1965	37.4	1975	April 4, 1975	32.0
1966	April 27, 1966	21.8	1976	April 24, 1976	65.6
1967	April 27, 1967	87.2	1977	May 27, 1977	28.4
1968	April 30, 1968	57.8	1978	July 6, 1978	57.8
1969	April 15, 1969	32.2	1979	August 7, 1979	35.5
1970	April 26, 1970	11.5	1980	April 19, 1980	60.8
1971	March 26, 1971	10.8			
		Qargha River above Qargha Reservoir			
1963	May 12, 1963	3.34	1974	March 21, 1974	5.60
1964	May 8, 1964	4.31	1975	April 4, 1975	3.50
1965	April 21, 1965	3.30	1976	April 22, 1976	4.00
1966	April 24, 1966	6.15	1977	April 15, 1977	3.55
1970	May 1, 1970	4.80	1978	July 6, 1978	5.00
1971	April 16, 1971	2.50	1979	May 19, 1979	4.10
1972	April 7, 1972	5.25	1980	April 5, 1980	6.11
1973	April 2, 1973	2.08			
		Qargha River below Qargha Reservoir			
1965	May 11, 1965	1.27	1973	July 18, 1973	0.70
1966	August 22, 1966	0.44	1974	October 1973	0.60
1967	June 18, 1967	0.58	1975	August 21, 1975	0.55
1968	May 2, 1968	1.20	1976	May 18, 1976	0.65
1969	June 1, 1969	0.93	1977	October 18, 1976	0.45
1970	June 20, 1970	0.63	1978	July 3, 1978	3.06
1971	June 7, 1971	0.50	1979	July 11, 1979	0.56
1972	May 14, 1972	5.90	1980	October 1, 1979	0.48
		Paghman River at Pul-i-Sokhta			
1963	May 12, 1963	17.80	1972	May 6, 1972	19.50
1964	April 10, 1964	15.50	1973	August 2, 1973	17.10
1965	May 7, 1965	16.00	1974	April 7, 1974	10.50
1966	April 27, 1966	5.56	1975	August 13, 1975	80.00
1967	April 27, 1967	34.80	1976	April 27, 1976	13.10
1968	April 30, 1968	48.80	1977	April 10, 1977	7.40
1969	April 19, 1969	4.65	1978	August 17, 1978	70.50
1970	July 7, 1970	4.00	1979	March 29, 1979	39.20
1971	April 12, 1971	3.42	1980	April 11, 1980	23.70

Table 8-2. Annual peak discharge for streamgages in the Kabul study area for the period of record.—Continued

[m^3/s, cubic meters per second]

Water year	Date	Peak discharge (m^3/s)	Water year	Date	Peak discharge (m^3/s)
		Logar River at Sang-i-Naweshta			
1962	March 31, 1962	36.60	1972	April 28, 1972	58.60
1963	May 13, 1963	52.90	1973	April 13, 1973	62.00
1964	April 13, 1964	65.30	1974	April 8, 1974	41.20
1965	April 25, 1965	85.00	1975	April 5, 1975	40.00
1966	April 14, 1966	27.90	1976	April 27, 1976	57.60
1967	April 28, 1967	95.00	1977	May 28, 1977	28.10
1968	April 9, 1968	36.00	1978	July 9, 1978	88.00
1969	April 20, 1969	34.00	1979	April 14, 1979	45.30
1970	November 12, 1969	25.30	1980	April 19, 1980	53.50
1971	March 26, 1971	19.70			
		Chakari River at Band-i-Amir Ghazi			
1965	July 5, 1965	1.46	1973	April 21, 1973	0.55
1966	May 1, 1966	1.00	1974	June 8, 1974	1.06
1967	May 23, 1967	1.26	1975	October 23, 1974	0.39
1968	December 9, 1967	1.67	1976	May 7, 1976	0.82
1969	March 13, 1969	0.55	1977	August 9, 1977	0.82
1970	July 17, 1970	0.96	1978	June 9, 1978	1.19
1971	May 1, 1971	0.55	1979	September 13, 1979	1.43
1972	June 18, 1972	1.36	1980	April 17, 1980	1.92
		Kabul River at Tangi-Gharu			
1960	May 2, 1960	175.0	1971	March 26, 1971	43.6
1961	April 18, 1961	98.0	1972	April 28, 1972	107.0
1962	November 15, 1961	39.5	1973	April 11, 1973	107.0
1963	May 19, 1963	165.0	1974	April 7, 1974	48.2
1964	April 10, 1964	158.0	1975	April 4, 1975	68.8
1965	April 25, 1965	156.0	1976	April 25, 1976	128.0
1966	April 26, 1966	79.7	1977	April 18, 1977	47.4
1967	April 28, 1967	192.0	1978	July 7, 1978	109.0
1968	April 30, 1968	115.0	1979	April 14, 1979	69.5
1969	April 19, 1969	85.5	1980	April 19, 1980	107.0
1970	July 7, 1970	101.0			
		Panjsher River at Gulbahar			
1960	July 10, 1960	584	1971	June 9, 1971	321
1961	June 5, 1961	515	1972	June 25, 1972	385
1962	June 10, 1962	488	1973	June 13, 1973	473
1963	June 20, 1963	520	1974	June 16, 1974	292
1964	July 4, 1964	569	1975	June 17, 1975	335
1965	July 15, 1965	300	1976	June 4, 1976	327
1966	June 19, 1966	335	1977	June 23, 1977	338
1967	June 12, 1967	358	1978	June 5, 1978	418

Table 8-2. Annual peak discharge for streamgages in the Kabul study area for the period of record.—Continued

[m3/s, cubic meters per second]

Water year	Date	Peak discharge (m^3/s)	Water year	Date	Peak discharge (m^3/s)
		Panjsher River at Gulbahar—Continued			
1968	July 8, 1968	412	1979	June 23, 1979	477
1969	June 20, 1969	424	1980	June 9, 1980	220
1970	June 3, 1970	350			
		Shatul River at Gulbahar			
1967	June 11, 1967	41.8	1974	June 4, 1974	21.6
1968	June 25, 1968	41.8	1975	June 17, 1975	30.9
1969	June 16, 1969	28.2	1976	July 6, 1976	24.5
1970	May 21, 1970	27.6	1977	June 22, 1977	20.7
1971	May 19, 1971	20.6	1978	June 5, 1978	27.0
1972	June 12, 1972	40.6	1979	June 13, 1979	35.0
1973	June 11, 1973	35.1			
		Ghorband River at Pul-i-Ashawa			
1960	April 18, 1960	146.0	1970	May 21, 1970	73.2
1961	June 5, 1961	139.0	1971	May 20, 1971	69.7
1962	June 11, 1962	84.4	1972	June 13, 1972	123.0
1963	May 15, 1963	96.2	1973	June 4, 1973	111.0
1964	April 11, 1964	93.0	1974	June 1, 1974	63.2
1965	June 13, 1965	118.0	1975	May 16, 1975	121.0
1966	June 18, 1966	108.0	1976	June 4, 1976	130.0
1967	April 27, 1967	161.0	1977	May 27, 1977	86.4
1968	June 10, 1968	131.0	1978	April 17, 1978	85.6
1969	June 17, 1969	97.5	1979	June 22, 1979	96.8
		Salang River at Bagh-i-Lala			
1962	April 25, 1962	43.8	1972	May 13, 1972	80.8
1963	May 14, 1963	92.8	1973	June 3, 1973	56.7
1965	June 13, 1965	50.0	1974	May 1, 1974	45.5
1966	April 25, 1966	60.6	1975	May 15, 1975	60.0
1967	April 27, 1967	124.0	1976	April 23, 1976	53.1
1968	April 29, 1968	76.1	1977	May 27, 1977	27.9
1969	April 14, 1969	91.0	1978	April 17, 1978	41.6
1970	April 15, 1970	58.5	1979	April 30, 1979	48.9
1971	May 19, 1971	22.4			
		Panjsher River at Shukhi			
1967	June 12, 1967	750	1974	June 18, 1974	380
1968	June 25, 1968	680	1975	June 17, 1975	451
1969	June 20, 1969	626	1976	June 4, 1976	482
1970	June 3, 1970	509	1977	June 23, 1977	392
1971	May 28, 1971	522	1978	July 7, 1978	590
1972	June 28, 1972	719	1979	June 22, 1979	558
1973	June 13, 1973	700	1980	June 9, 1980	452

Table 8-3. Probability of occurrence of annual low discharge for the period of record at streamgages in the Kabul study area.

[m^3/s, cubic meters per second]

Nonexceedance probability	Recurrence interval (years)	Minimum mean discharge (m^3/s) Number of consecutive days					
		1	3	7	14	30	60
Kabul River at Tangi Saidan							
0.05	20	0.000	0.009	0.017	0.045	0.073	0.089
0.10	10	0.008	0.017	0.029	0.060	0.093	0.115
0.20	5	0.023	0.033	0.052	0.084	0.124	0.153
0.50	2	0.089	0.104	0.135	0.159	0.208	0.254
Qargha River above Qargha Reservoir							
0.05	20	0.023	0.023	0.023	0.023	0.023	0.025
0.10	10	0.024	0.025	0.025	0.025	0.026	0.029
0.20	5	0.027	0.028	0.029	0.029	0.031	0.036
0.50	2	0.034	0.035	0.037	0.040	0.044	0.053
Paghman River at Pul-i-Sokhta							
0.05	20	0.000	0.000	0.000	0.000	0.000	0.000
0.10	10	0.000	0.000	0.000	0.000	0.000	0.004
0.20	5	0.000	0.003	0.006	0.006	0.007	0.008
0.50	2	0.012	0.013	0.015	0.017	0.021	0.026
Logar River at Sang-i-Naweshta							
0.05	20	0.000	0.000	0.000	0.004	0.009	0.020
0.10	10	0.000	0.005	0.008	0.008	0.016	0.034
0.20	5	0.012	0.014	0.018	0.019	0.033	0.063
0.50	2	0.068	0.069	0.077	0.096	0.124	0.205
Chakari River at Band-i-Amir Ghazi							
0.05	20	0.000	0.000	0.000	0.008	0.009	0.01
0.10	10	0.007	0.007	0.007	0.009	0.01	0.012
0.20	5	0.009	0.009	0.009	0.011	0.013	0.015
0.50	2	0.014	0.014	0.014	0.015	0.02	0.025
Kabul River at Tangi-Gharu							
0.05	20	0.000	0.000	0.013	0.018	0.021	0.045
0.10	10	0.011	0.012	0.022	0.030	0.037	0.069
0.20	5	0.028	0.031	0.043	0.057	0.069	0.115
0.50	2	0.112	0.125	0.141	0.181	0.217	0.316

Table 8-3. Probability of occurrence of annual low discharge for the period of record at streamgages in the Kabul study area.—Continued

[m³/s, cubic meters per second]

Nonexceedance probability	Recurrence interval (years)	Minimum mean discharge (m³/s)					
		Number of consecutive days					
		1	3	7	14	30	60
Panjsher River at Gulbahar							
0.05	20	6.39	6.47	6.58	6.72	6.85	7.20
0.10	10	6.88	7.00	7.14	7.28	7.44	7.78
0.20	5	7.53	7.69	7.85	8.01	8.19	8.53
0.50	2	8.91	9.14	9.33	9.51	9.75	10.10
Shatul River at Gulbahar							
0.05	20	0.006	0.006	0.007	0.100	0.011	0.016
0.10	10	0.007	0.007	0.009	0.012	0.014	0.020
0.20	5	0.009	0.010	0.012	0.015	0.019	0.027
0.50	2	0.018	0.019	0.023	0.030	0.038	0.053
Ghorband River at Pul-i-Ashawa							
0.05	20	3.27	3.34	3.43	3.57	3.76	4.12
0.10	10	3.80	3.89	3.99	4.15	4.39	4.80
0.20	5	4.54	4.65	4.76	4.95	5.23	5.69
0.50	2	6.26	6.44	6.58	6.78	7.10	7.62
Salang River at Bagh-i-Lala							
0.05	20	1.28	1.54	1.58	1.63	1.73	1.86
0.10	10	1.41	1.66	1.70	1.75	1.86	1.99
0.20	5	1.59	1.81	1.87	1.92	2.03	2.17
0.50	2	2.00	2.17	2.25	2.30	2.41	2.55
Panjsher River at Shukhi							
0.05	20	20.7	20.9	21.2	21.5	21.8	23.0
0.10	10	21.6	21.8	22.0	22.4	22.8	24.0
0.20	5	22.7	22.8	23.1	23.4	23.9	25.2
0.50	2	24.8	24.9	25.1	25.4	26.2	27.5

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Appendix 9. Groundwater Levels

Contents

Appendix 9. Groundwater Levels

Groundwater-level conditions in the Logar, Central Kabul, Deh Sabz, Paghman and Upper Kabul, and Shomali subbasins are discussed below with references to historical conditions where possible. Groundwater-level hydrographs for the subbasins of the Kabul Basin are provided by Akbari and others (2007). Monthly groundwater data do not exist for the Panjsher River subbasin; however, conditions are likely to be similar to the northernmost parts of the Shomali subbasin where the aquifer is influenced by Panjsher River losses.

Logar Subbasin

The depth to water on the western bank of the Logar River (Logar aquifer) is reported to be between 30 to 80 centimeters (cm) in the lower flat-lying area and between 1.5 and 2 meters (m) in the higher regions (elevations) during the period of investigation (2003–2005). Böckh (1971) reported that the water levels on the eastern bank of the Logar River ranged from around 5 to 10 m below land surface and that the depth to water fluctuated between 1 and 2 m in response to pumping for irrigation. The large difference between the depth to water on the west and east banks of the Logar River were attributed to differences in land-surface elevation. The Kabul aquifer generally has depths to water that range from 2 to 12 m and water-level fluctuations up to 5 m. Water levels in 1965 were from 2 to 5 m below land surface. The depth to water in the Paghman aquifer is very shallow near the center of the basin and increases towards the valley sides. Depth-to-water measurements made in 1962–1963 indicate a water level of 19 m below land surface near the confluence of the Cheltan and Paghman streams.

The Logar subbasin includes urban population centers and rural, agricultural land. Nine monitoring wells in the Logar subbasin ranged in total depth from 25 to 79.1 m. The surficial geology at the wells varied from Quaternary loess to Quaternary conglomerate and sandstone. Depth-to-water measurements under static conditions ranged from a minimum of 1.5 m (1,783.4 m above sea level) adjacent to the Logar River during May 2005 to a maximum of 10.2 m (1,781.1 m above sea level) during the fall of 2004 and 2006 at a well not in the vicinity of any streams or rivers. Seasonal water-level fluctuations from fall 2005 through spring 2006 ranged from about 1.3 to 4 m in the Logar subbasin. Water-level increases of up to 3.9 m from October 2004 until June 2006 were measured in a well along the Logar River. Many of the wells along the Logar River are municipal water-supply wells that are frequently pumped. Taking this into account, there does appear to be a strong seasonal recharge component that can be correlated to times of peak flow during winter and spring in the Logar River. Depth to water in one well rose from 9.3 m (1,783.3 m above sea level) in early January 2005 to 5 m (1,787.5 m above sea level) in May 2005. This change in water level corresponded to near-normal winter and spring precipitation and corresponding flow in the Logar River.

Central Kabul Subbasin

The Central Kabul subbasin includes the primary population center of Afghanistan (city of Kabul) in the western part of the subbasin and more rural lands in the eastern part of the subbasin. Twenty-four monitoring wells in the Central Kabul subbasin ranged in total depth from 6.6 to 160 m. One well was located on an outcrop of gneiss; at all other well sites, the surface geology consisted of Quaternary loess, fan alluvium and colluvium, or conglomerate and sandstone. Depth-to-water measurements under static conditions ranged from a minimum of about 2.5 m (1,790 m above sea level) during June 2005 to a maximum of about 23 m (1,778 m above sea level) during January and February 2006. Monitoring wells that have water levels not affected by pumping have seasonal fluctuations from 0.5 to 3 m. The water level in the supply well on the grounds of the Afghanistan Geological Survey building had a seasonal fluctuation of about 2 m. In general, it appears the wells near the Kabul River had increasing water levels during the monitoring period, and wells that are distant from the river had decreases in water level. The water-level summary plot for Well 208 shows a recovery of approximately 9 m from a dynamic water-level measurement in March 2005 to a static water-level measurement in early April 2005. The water-level measurement in this well in late April 2005 recorded a drop of about 8 m because of pumping. Larger water-level fluctuations caused by pumping were recorded in the Khair Khana wells; pumping-induced drawdown was up to 25 m.

Deh Sabz Subbasin

The Deh Sabz subbasin is a sparsely populated mixed agricultural and industrial area. Nine monitoring wells in the Deh Sabz subbasin ranged in depth from 7.2 to 150 m. The surficial geology at the wells varied from Quaternary loess to Quaternary conglomerate and sandstone. There are no perennial rivers or streams in this subbasin, although some ephemeral streams and some perennial springs discharge from the base of the mountains on the east side of this subbasin. Depth-to-water measurements under static conditions ranged from a minimum of 4 m (1,963.6 m above sea level) measured in early March 2007 to a maximum of 40 m (1,812.6 m above sea level) in August 2006. Seasonal water-level fluctuations ranged from 0.5 to 9 m. Seasonal water-level fluctuations are thought to be attributed to precipitation that falls locally on the valley floor or mountains to the east. Two wells in the Deh Sabz subbasin showed generally declining water levels during the monitoring period ranging from 0.9 m from April 2005 to September 2006 in one well and 1.0 m from August 2005 to May 2006 in another well.

The water level in a well that was 7.2 m deep increased approximately 3 m from August 2006 to March 2007. In a 150-m deep well, the static water level increased about 3 m from March 2005 to March 2007. The drawdown during pumping in this well ranged from approximately 20 m to as much as 40 m. Recovery after pumping stopped was fairly rapid. The water-level elevation in mid-May 2006 under dynamic conditions was 1,784.6 m above sea level. The water-level elevation measured under static conditions in early June 2006 was 1,822.6 m above sea level, so the water level had increased about 38 m.

Paghman and Upper Kabul Subbasin

The Paghman and Upper Kabul subbasin includes the urban population centers of the western city of Kabul, and more rural agrarian lands in the western part of the subbasin. Twelve monitoring wells in the Paghman and Upper Kabul subbasin ranged in depth from 4.9 to 99.7 m. One well was located on an outcrop of gneiss; all other wells were in Quaternary loess, alluvium, or colluvium. Five of the monitoring wells are municipal water-supply wells. Three are located approximately 1 km west of the Kabul River near the confluence of the Kabul River and Paghman Stream. The other two are located much further west of the Kabul River and within a kilometer of the Paghman Stream. Depth-to-water measurements under static conditions ranged from 3 m (1,805.6 m above sea level) to 28 m (1,840.3 m above sea level). Seasonal water-level fluctuations from fall 2005 through spring 2006 ranged from about 0.5 to 3 m. The water levels in two wells declined from August 2004 until February 2007. One well declined about 3 m and the other about 8 m. These two wells were approximately 0.8 km apart and north of the Paghman Stream. Three wells had increases in water levels ranging from 3 to 5 m from February 2005 through March 2007. Only one municipal supply well had static water-level measurements spanning a fall-winter-spring precipitation cycle. Measurements under static conditions in this well from November 2004 until June 2005 showed an increase in the water level from 1,802.5 m above sea level to 1,804.6 m above sea level, an increase of 2.1 m. The water levels in wells close to the Kabul River had larger seasonal water-level increases than wells that are not near major surface-water sources.

Shomali Subbasin

The Shomali subbasin is a predominantly rural area that contains the largest irrigated agricultural area in the Kabul Basin. A number of springs discharge from the mountains on the western border of this subbasin. The flow from these springs is the source for a number of small perennial streams in the western part of the Shomali subbasin. The water in these streams is used for irrigation with much of the water being diverted to irrigation canals. As a result, these small streams eventually dry up and do not contribute flow to the Barik Ab River, the largest ephemeral stream in the subbasin. Fifteen monitoring wells in the Shomali subbasin ranged in depth from 9 to 102 m. The surficial geology at the well locations consisted of Quaternary loess or Quaternary fan alluvium and colluvium. The range of depth to water under static conditions was from 3.4 m below land surface in two wells (1,540 m above sea level in October 2005 and 1,877.7 m above sea level in May 2006) to 27.8 m below land surface (1,784.9 m above sea level) in August 2004. Seasonal water-level fluctuations ranged from approximately 0.5 to 8 m. The largest increase in the water level was approximately 13 m from 1,786.7 m above sea level in March 2005 to 1,799.7 m above sea level in May 2006. While the water level in most wells increased during the monitoring period, one well appeared to have an overall decline in water level from 1,644.4 m above sea level in late August 2004 to 1,642.9 m above sea level in October 2006. This decline may be attributed to pumping of the well before the October 2006 measurement. Two wells showed a steady increase in water levels during the monitoring period with minimal seasonal fluctuations. The seasonal high water levels in six wells increased with time and in three wells decreased with time. The deepest well in the monitoring network in the Shomali subbasin (102-m deep) had about a 0.5 m decline in water level between the July 2005 maximum and the late September 2005 minimum. The water level in this well increased during the monitoring period by about 8 m from 1,791.7 to 1,799.7 m above sea level. The water-level maximums in most wells were prior to mid-July, and in 2006 were prior to mid-June. Ephemeral streams in the Shomali subbasin are potential sources of recharge, especially during years when the Paghman Mountains receive near normal precipitation.

References Cited

Akbari, M.A., Tahir, M., Litke, D.W., and Chornack, M.P., 2007, Groundwater levels in the Kabul Basin, Afghanistan, 2004–07: U.S. Geological Survey Open-File Report 2007–1294, 46 p.

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Appendix 10. Water-Quality Data

Appendix 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan

[Comment: CHC or 3H refer to appendix table 10-1B. m, meters; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; g/L, grams per liter; samples analyzed at USGS laboratory (R) unless indicated as USGS Denver laboratory (D); milligrams per liter; Alk, titration alkalinity; <, less than; >, greater than or equal to; --, not applicable; µg/L, microgram per liter; ICPMS, inductively coupled plasma mass spectrometry; FU, filtered unacidified; FA, filtered acidified; NFA, not acidified in the field]

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Sample water level (m)	Water tempe-rature (°C)	Spec. cond. (µS/cm)	Total dissolved solids (g/L)	pH field	O_2 (mgL)	NO_2 N field (mg/L)	NO_3 N field (mg/L)	Total coli count per 100 mL
2.1	Well 2.1	09-25-04	0000	Eastern Front		20.2	338		8.23	4.1	0	0-1	1
2.1	Well 2.1	06-07-06	0945	Eastern Front	41.47	20.5	351	0.17	8.08		0	0-1	4.1
3	Well 3	10-31-04	0000	Deh Sabz	16.24	15.4			7.8		0	1-2	1
6	Karez N6	05-10-06	1140	Eastern Front		16.3	546	0.24	8.32		0	1-2	
7	Well 7	10-31-04	0000	Eastern Front	5.98	15	347		7.4		0	1-2	1
7	Well 7	06-04-06	0945	Eastern Front	5.47	12.6	452	0.2	7.25		0	0-1	
8	Well 8	11-02-04	0000	Deh Sabz	15.84	15.5	1,700		7.28		0	2-5	3
8	Well 8	06-07-06	1025	Deh Sabz	14.36	17.4	1,832	0.88	7.43		0	1-2	>2,420
9	Well 9	09-25-04	0000	Deh Sabz	23.4	18.5	540		7.8	4.3	0	1-2	200
10	Karez 10	05-10-06	1205	Eastern Front			667	0.32	8.18		0	1-2	
11	Well 11	11-02-04	0000	Deh Sabz		16.8			7.6		0	1-2	1
12	Well 12	11-18-04	0000	Deh Sabz	14.07	15.9	2,275		7.5		0	5-10	>2,420
13	Well 13	11-04-04	0000	Deh Sabz		18.5			7.81		0	1-2	200
13	Well 13	05-16-06	1200	Deh Sabz	32.1	20.1	507	0.22	7.69		0	1-2	
15	Well 15	11-04-04	0000	Deh Sabz	15.72	17.3	2,068		7.25		0	1-2	1
15	Well 15	05-30-06	1510	Deh Sabz	16.88	15.8	2,374	1.11	7.06		0	1-2	18
16	Well 16	11-09-04	0000	Shomali		15.6	1,062		7.64		0	5	1
17	Well 17	11-16-04	0000	Shomali	18.53	14.2	584		7.42		0	2-5	1
18.2	Well 18.2	11-16-04	0000	Shomali		13.6	491		7.53		0	1-2	200
20	Well 20	11-11-04	0000	Western Front	14.32	11.6	293.6		7.65		0	1-2	200
20	Well 20	06-10-06	0925	Western Front	10.33	13.2	335	0.15	7.18		0	2-5	2,419
21	Well 21	11-08-04	0000	Western Front	14.7	14	310.3		7.81		0	1-2	2
21	Well 21	06-12-06	0920	Western Front	12.02	14	382	0.17	7.6		0	0-1	32
22.1	Well 22.1	06-12-06	0945	Shomali	13.85	14.1	443	0.22	7.21		0-0.15	2-5	2,419
23	Well 23	11-11-04	0000	Shomali		14.7	507		7.78		0	1-2	1
24	Well 24	09-22-04	0000	Shomali	12.21	13.9	567		7.16	8.5	0	2-5	1
24	Well 24	06-14-06	0950	Shomali	10.01	15.5	588	0.27	7.12		0	1-2	1
25	Well 25	09-27-04	0000	Shomali	21	15.5	615		7.29	12.8	0	5	1
25	Well 25	06-14-06	1015	Shomali	20.01	15.8	636	0.29	7.27		0	2-5	72.7
26	Well 26	11-09-04	0000	Shomali		14.8	581		7.17		0	2-5	2
27	Well 27	11-09-04	0000	Shomali		14.8	303		8.05		0	1-2	2
28	Well 28	09-27-04	0000	Shomali	19.34	14.9	602		7.41	9.9	0	2-5	200
28	Well 28	05-23-06	1300	Shomali	21.35	13.7	589	0.27	7.3		0	1-2	22.4
29	Well 29	11-01-04	0000	Shomali		15.4	1,030		7.17	8.3	0	3-5	27
31.2	Well 31.2	10-30-04	0000	Shomali	23.52	13.7	632		7.5	9	0	2-5	200
33	Well 33	10-30-04	0000	Western Front	5.2	14.7	536		7.5	3.7	0	1-2	1
33	Well 33	05-23-06	1030	Western Front	3.4	16.3	615	0.27	7.25		0	1-2	1,046
35	Well 35	11-07-04	0000	Deh Sabz		17.8	521		7.68		0	1-2	78
36	Well 36	11-07-04	0000	Deh Sabz		17	965		7.24		0	1-2	12
37	Well 37	11-07-04	0000	Deh Sabz	15.1	18.2	793		6.93		0	1-2	1,046
37	Well 37	05-14-06	1000	Deh Sabz	15.14	18.8	600	0.36	7.43		0	1-2	1,733
38	Well 38	11-01-04	0000	Shomali		14.9	641		7.38	8.5	0	2-5	5
39.2	Well 39.2	11-10-04	0000	Shomali	11.13	15.4	682		7.33	8.2	0	1-2	1
41	Well 41	11-06-04	0000	Western Front	4.82	15.8	262		7.78	9	0	2	2
41	Well 41	05-28-06	0950	Western Front	3.51	18.1	248	0.11	7.62		0	1-2	5.2
42	Well 42	11-10-04	0000	Shomali	7.25	14.3	672		7.51	5	0	1-2	200
42	Well 42	05-28-06	0810	Shomali	6.98	15.8	706	0.33	7.38		0	1-2	1,986
43	Well 43	05-28-06	0925	Western Front	5.05	15.2	629	0.29	7.08		0	0-1	>2,420
45	Well 45	11-08-04	0000	Western Front	8.49	16.7	733		7.34	6.4	0	1-2	3
45	Well 45	05-30-06	1220	Western Front	7.68	18.2	759	0.33	7.05		0	1-2	1
47	Well 47	05-30-06	1345	Shomali	6.43	16.1	1,490	0.65	7.23		0	1-2	1,986
52	Well 52	09-22-04	0000	Western Front	21.7	13.5	472.6		7.08	7.6	0	2-5	200
52	Well 52	06-10-06	1030	Western Front	17.46	13.8	518	0.24	7.14		0	1-2	>2,420

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month-day-year)	*E. coli* count per 100 mL	pH lab	Spec. cond. Lab (µS/cm)	NO_4 N (mg/L)	NO_2 N mg/L)	NO_2-NO_3N (mg/L)	NO_3 N (mg/L)	NO_3 NO_3 (mg/L)	Total N (mg/L)	PO_4 P (mg/L)	Ca (mg/L)	Mg (mg/L)	Hardness (mg/L)	Na (mg/L)
2.1	09-25-04	1	8.2	323		0.004	0.03					17	10.7	86.5	42.4
2.1	06-07-06	4.1													
3	10-31-04	1				0.08	1.24	1.2	5.3			38	27.4	207.7	16.2
6	05-10-06							2.46	10.9			51.4	29.3	249	22.1
7	10-31-04	1				0.004	0.28					65	26.2	270.2	2
7	06-04-06	219													
8	11-02-04	1				0.03	2.2	2.2	9.7			97	90.2	613.7	232
8	06-07-06	461													
9	09-25-04	1	8	491		0.004	3.06					36	29.7	212.2	32.8
10	05-10-06							2.07	9.18			76.3	37.2	343.7	18.1
11	11-02-04	1				0.004	3.71					54	18.5	211	18.3
12	11-18-04	19				0.04	11.6	11.6	51.4			96	126	758.6	183
13	11-04-04	1				0.02	3.7	3.7	16.4			47	14.7	177.9	32.6
13	05-16-06	12						3.30	14.6			49.8	14.7	184.9	35.1
15	11-04-04	1				0.01	2.72	2.7	12			108	121	768	256
15	05-30-06	1													
16	11-09-04	1				0.004	7.07					74	31.1	312.9	103
17	11-16-04	1				0.02	3.85	3.8	16.8			53	31.5	262.1	26.8
18.2	11-16-04	1				0.004	2.14					73	16.6	250.6	9.1
20	11-11-04	41				0.02	2.89	2.9	12.8			44	6.9	138.3	3.2
20	06-10-06	0													
21	11-08-04	1	7.9	287		0.02	1.06	1	4.4			41	10.2	144.4	5.4
21	06-12-06	1													
22.1	06-12-06	4.1													
23	11-11-04	1				0.04	1.74	1.7	7.5			68	14.9	231.2	10.3
24	09-22-04	1	7.3	513		0.004	3.16					84	16.8	278.9	11.2
24	06-14-06	0													
25	09-27-04	1	7.6	572		0.004	7.61	7.6	33.6			84	24.1	309	11
25	06-14-06	1													
26	11-09-04	1				0.004	7					80	18.5	276	14.7
27	11-09-04	1				0.02	1.73	1.7	7.5			42	8.1	138.2	6.5
28	09-27-04	9	7.7	554		0.04	4.6	4.6	20.4			70	28.2	290.9	15.8
28	05-23-06	3						3.73	16.5			67.8	28.1	285	16.4
29	11-01-04	1				0.03	4.7	4.7	20.8			127	49	518.9	76.6
31.2	10-30-04	118				0.02	5.11	5.1	22.6			89	22.9	316.5	14.2
33	10-30-04	1				0.004	2.11					81	16.8	271.4	10.5
33	05-23-06	1						4.00	17.7			92	19	308	11.6
35	11-07-04	1				0.007	4.34	4.3	19			44	21.1	196.8	28.6
36	11-07-04	1				0.004	2.93					84	49.1	412	48.3
37	11-07-04	1				0.005	3.88	3.9	17.3			76	25.2	293.6	52
37	05-14-06	308						3.80	16.8			70.3	23	270.3	53.6
38	11-01-04	1				0.004	6.35					81	39.2	363.7	36.3
39.2	11-10-04	1				0.004	1.87	1.9	8.4			59	32.1	279.5	32.9
41	11-06-04	1				0.004	1.64	1.6	7.1			37	4.9	112.6	7.4
41	05-28-06	1													
42	11-10-04	3				0.004	2.97					65	29.3	283	36.6
42	05-28-06	18.3						1.79	7.94			66.8	31.4	296.1	43.2
43	05-28-06	1													
45	11-08-04	1				0.004	2.77					74	42	357.8	26.9
45	05-30-06	1													
47	05-30-06	1						4.18	18.5			101.3	70.5	542.6	108
52	09-22-04	1	7.4	422		0.02	2.81	2.8	12.4			74	11.4	231.7	7.9
52	06-10-06	125													

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	SAR	K (mg/L)	Alk mg/L as $CaCO_3$ (D)	Alk mg/L as HCO_3 (R)	Alk mg/L as HCO_3 (R&D)	Alk mg/L as $CaCO_3$ (R&D)	sum meq cations	sum meq anions	Percent charge imbalance
2.1	Well 2.1	09-25-04	0000	Eastern Front	1.98	2.9	140		170.7	140	3.69	3.72	-0.22
2.1	Well 2.1	06-07-06	0945	Eastern Front									
3	Well 3	10-31-04	0000	Deh Sabz	0.49	1.3	212		258.5	212	4.99	4.88	0.52
6	Karez N6	05-10-06	1140	Eastern Front	0.61	1.2		251.7	251.7	206	6.07	5.62	1.95
7	Well 7	10-31-04	0000	Eastern Front	0.05	0.6	217		264.6	217	5.59	4.71	4.28
7	Well 7	06-04-06	0945	Eastern Front									
8	Well 8	11-02-04	0000	Deh Sabz	4.08	5.8	343		418.2	343	22.82	22.73	0.10
8	Well 8	06-07-06	1025	Deh Sabz									
9	Well 9	09-25-04	0000	Deh Sabz	0.98	1.4	194		236.5	194	5.81	5.64	0.74
10	Karez 10	05-10-06	1205	Eastern Front	0.42	1.4		380.0	380.0	312	7.82	7.54	0.93
11	Well 11	11-02-04	0000	Deh Sabz	0.55	0.9	184		224.3	184	5.10	4.79	1.55
12	Well 12	11-18-04	0000	Deh Sabz	2.89	5.3	228		278.0	228	23.70	22.85	0.91
13	Well 13	11-04-04	0000	Deh Sabz	1.06	4.3	120		146.3	120	5.13	4.64	2.53
13	Well 13	05-16-06	1200	Deh Sabz	1.12	4.5		168.2	168.2	138	5.39	5.38	0.04
15	Well 15	11-04-04	0000	Deh Sabz	4.02	3.1	385		469.4	385	26.99	25.62	1.30
15	Well 15	05-30-06	1510	Deh Sabz									
16	Well 16	11-09-04	0000	Shomali	2.53	5.3	202		246.3	202	10.98	10.70	0.63
17	Well 17	11-16-04	0000	Shomali		2.4	251		306.0	251	6.58	5.53	4.29
18.2	Well 18.2	11-16-04	0000	Shomali		3	256		312.1	256	5.54	5.35	0.88
20	Well 20	11-11-04	0000	Western Front		3	138		168.3	138	3.00	2.91	0.83
20	Well 20	06-10-06	0925	Western Front									
21	Well 21	11-08-04	0000	Western Front	0.2	3.1	157		191.4	157	3.24	3.27	-0.27
21	Well 21	06-12-06	0920	Western Front									
22.1	Well 22.1	06-12-06	0945	Shomali									
23	Well 23	11-11-04	0000	Shomali	0.29	3.9	240		292.6	240	5.22	5.12	0.49
24	Well 24	09-22-04	0000	Shomali	0.29	4.3	248		302.4	248	6.23	5.46	3.31
24	Well 24	06-14-06	0950	Shomali									
25	Well 25	09-27-04	0000	Shomali	0.27	3.2	287		349.9	287	6.82	6.33	1.85
25	Well 25	06-14-06	1015	Shomali									
26	Well 26	11-09-04	0000	Shomali	0.39	4.4	240		292.6	240	6.33	5.39	4.02
27	Well 27	11-09-04	0000	Shomali	0.24	3.9	150		182.9	150	3.17	3.15	0.16
28	Well 28	09-27-04	0000	Shomali	0.4	3.8	274		334.1	274	6.70	6.07	2.45
28	Well 28	05-23-06	1300	Shomali	0.42	4		330.0	330.0	271	6.61	6.15	1.81
29	Well 29	11-01-04	0000	Shomali	1.46	4.1	204		248.7	204	13.98	11.65	4.55
31.2	Well 31.2	10-30-04	0000	Shomali	0.35	3.2	199		242.6	199	7.11	4.58	10.82
33	Well 33	10-30-04	0000	Western Front	0.28	4.1	201		245.1	201	6.05	4.20	8.99
33	Well 33	05-23-06	1030	Western Front	0.29	4.2		370.0	370.0	303	6.83	6.35	1.82
35	Well 35	11-07-04	0000	Deh Sabz	0.89	1	155		189.0	155	5.28	5.06	1.05
36	Well 36	11-07-04	0000	Deh Sabz	1.04	1.5	207		252.4	207	10.54	9.68	2.15
37	Well 37	11-07-04	0000	Deh Sabz	1.32	5.8	208		253.6	208	8.37	8.13	0.70
37	Well 37	05-14-06	1000	Deh Sabz	1.42	5		204.8	204.8	168	7.94	7.52	1.36
38	Well 38	11-01-04	0000	Shomali	0.83	6.6	351		428.0	351	9.15	8.56	1.67
39.2	Well 39.2	11-10-04	0000	Shomali	0.86	4.2	289		352.4	289	7.24	6.97	0.95
41	Well 41	11-06-04	0000	Western Front	0.3	2.4	121		147.5	121	2.65	2.62	0.32
41	Well 41	05-28-06	0950	Western Front									
42	Well 42	11-10-04	0000	Shomali	0.95	4.1	287		349.9	287	7.45	6.55	3.22
42	Well 42	05-28-06	0810	Shomali	1.09	4.5		420.0	420.0	344	8.02	7.81	0.68
43	Well 43	05-28-06	0925	Western Front									
45	Well 45	11-08-04	0000	Western Front	0.62	5.3	331		403.6	331	8.60	7.32	4.03
45	Well 45	05-30-06	1220	Western Front									
47	Well 47	05-30-06	1345	Shomali	2.02	8.5		490.0	490.0	402	16.02	15.58	0.70
52	Well 52	09-22-04	0000	Western Front	0.23	3	208		253.6	208	5.09	4.64	2.32
52	Well 52	06-10-06	1030	Western Front									

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/day/year)	Cl (mg/L)	SO_4 (mg/L)	F (mg/L)	Br (mg/L)	SiO_2 (mg/L)	ROE	SOC	ROESOC	Ion Balance Charge	Ion Balance Percent	ROESC	Al (µg/L)	Sb (µg/L)	As (µg/L)	As (µg/L) (R or D)
2.1	09-25-04	7.6	33.8	0.09	0.06	13	216					0.64	3.4	0.1		2.2
2.1	06-07-06					2.9										
3	10-31-04	5.3	23.8	0.21		20	265			-0.08	-0.79		1.9	0.1		3
6	05-10-06	15.5	50.5	0.36	0.09	18.1		351		-0.73	-5.78		315	0.1	1.3	1.3
7	10-31-04	1.3	16.2	0.36		15	248					0.71	1.1	0.1		0.6
7	06-04-06															
8	11-02-04	240	437	0.43	0.78	20	1,400	1,339	1.05	-0.38	-0.83	0.82	4	0.1		2.1
8	06-07-06															
9	09-25-04	24.3	51.6	0.09	0.18	19	334					0.62	2.5	0.1		1.9
10	05-10-06	8.3	51.6	0.16	<0.05	17.1				-1.36	-8.11		34	1.6	0.5	0.5
11	11-02-04	10.9	38.8	0.35	0.1	20	284						1.7	0.2		0.5
12	11-18-04	370	377	0.66	1.04	22	1,460	1,369	1.07	-0.41	-0.88	0.64	2	0.2		1.3
13	11-04-04	28.6	68.9	0.46		30	321			0.18	1.8		13.5	0.1		0.8
13	05-16-06	29.2	86.3	0.54	0.08	30.4		366		-0.88	-7.59		3	<0.1	0.9	0.9
15	11-04-04	315	434	0.23	0.9	23	1,590	1,504	1.06	0.75	1.44	0.77	3.2	0.1		0.8
15	05-30-06															
16	11-09-04	57.6	242	0.46	0.37	26	705					0.66	0.8	0.1		0.8
17	11-16-04	7.8	14.3	0.52	0.08	27	343	331	1.04	0.66	5.37	0.59	1.4	0.1		3.2
18.2	11-16-04	3.8	6	0.16	0.06	23	285					0.58	0.8	0.1		0.9
20	11-11-04	2.8	3.3	0.14	0.05	18	181			-0.13	-2.18	0.62	1.7	0.1		0.2
20	06-10-06															
21	11-08-04	3.2	2	0.07		24	191			-0.14	-2.16	0.62	1.3	0.1		0.2
21	06-12-06															
22.1	06-12-06															
23	11-11-04	6.8	6.2	0.19	0.07	25	286	287	1	-0.07	-0.68	0.56	0.8	0.1		0.6
24	09-22-04	6.8	14.8	0.17	0.04	23	298					0.53	1.2	0.1		0.1
24	06-14-06															
25	09-27-04	11.6	13	0.21	0.05	25	383	378	1.01	-0.14	-1.03	0.62	1.1	0.1		0.7
25	06-14-06															
26	11-09-04	9.7	15.3	0.14	0.05	24	347					0.6	0.8	0.1		0.4
27	11-09-04	2.7	3.8	0.08	0.05	19	177			-0.13	-2.01	0.58	0.9	0.1		0.9
28	09-27-04	9.1	16.2	0.32	0.04	27	337	355	0.95	0.2	1.54	0.56	1.5	0.1		0.2
28	05-23-06	11.2	20.3	0.19	<0.05	26.3				-1.09	-7.71		<1	<0.1	0.4	0.4
29	11-01-04	111	213	0.38	0.41	26	802	751	1.07	1.83	7.09	0.78	3.1	0.1		0.1
31.2	10-30-04	12.5	11.9	0.19		23	298			2.08	17.42	0.47	4.2	0.1		0.4
33	10-30-04	4	3.5	0.22		23	286					0.53	1.2	0.1		0.2
33	05-23-06	4.46	7.8	0.19	<0.05	23.7				-1.2	-8.15		<1	<0.1	0.2	0.2
35	11-07-04	26.5	58.2	0.23	0.2	19	312	311	1	-0.16	-1.53	0.6	1.7	0.1		1.4
36	11-07-04	64.9	178	0.2	0.39	21	636					0.66	1.5	0.1		0.9
37	11-07-04	39.8	137	0.39	0.23	31	521	510	1.02	-0.13	-0.8	0.66	8.1	0.1		0.4
37	05-14-06	41.2	144	0.38	0.17	30.6		508		-0.67	-4.08		1	<0.1	1.1	1.1
38	11-01-04	25.9	39.1	0.34	0.09	27	482					0.75	0.9	0.1		0.6
39.2	11-10-04	20.4	29.6	0.3	0.1	24	378	384	0.98	0.02	0.15	0.55	0.9	0.1		0.6
41	11-06-04	4	4.1	0.07	0.06	18	156	158	0.99	-0.1	-1.82	0.6	1.2	0.1		0.5
41	05-28-06															
42	11-10-04	15.9	17.6	0.24	0.07	24	389					0.58	5.1	0.1		0.3
42	05-28-06	18	19.9	0.24	<0.05	24.2				-1.53	-8.82		3	<0.1	0.9	0.9
43	05-28-06															
45	11-08-04	15.4	12.9	0.22		28	413					0.56	1.9	0.1		0.9
45	05-30-06															
47	05-30-06	139	174	0.28	0.22	28.0		942		-1.88	-5.62		2	<0.1	1.2	1.2
52	09-22-04	10	9.6	0.09	0.03	23	264			0.21	2.15	0.56	2.2	0.1		0.3
52	06-10-06															

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Ba (µg/L)	Be (µg/L)	B (µg/L)	Cd (µg/L)	Cr (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L)	D	Fe (µg/L)
2.1	Well 2.1	09-25-04	0000	Eastern Front	53	0.03	24	0.02	0.4	3.28	0.4	12.6		
2.1	Well 2.1	06-07-06	0945	Eastern Front										
3	Well 3	10-31-04	0000	Deh Sabz	85	0.03	45	0.02	5.2	1.25	1.2	9		
6	Karez N6	05-10-06	1140	Eastern Front	49		120	<0.05	3	0.27	1.1			300
7	Well 7	10-31-04	0000	Eastern Front	32	0.03	11	0.02	0.4	0.23	0.4	7		
7	Well 7	06-04-06	0945	Eastern Front										
8	Well 8	11-02-04	0000	Deh Sabz	30	0.03	2,000	0.02	8.3	2.33	3.3	7		
8	Well 8	06-07-06	1025	Deh Sabz										
9	Well 9	09-25-04	0000	Deh Sabz	92	0.03	68	0.02	16	0.2	0.7	3.6		
10	Karez 10	05-10-06	1205	Eastern Front	60		110	<0.05	2	0.13	1.2			30
11	Well 11	11-02-04	0000	Deh Sabz	35	0.03	78	0.02	1.7	1.52	1.7	8		
12	Well 12	11-18-04	0000	Deh Sabz	47	0.03	1,060	0.02	17	0.44	2	9		
13	Well 13	11-04-04	0000	Deh Sabz	24	0.03	139	0.02	0.8	0.39	0.6	16		
13	Well 13	05-16-06	1200	Deh Sabz	22		130	<0.05	<1	0.25	0.7			<20
15	Well 15	11-04-04	0000	Deh Sabz	30	0.03	3,030	0.02	26	2.15	2.3	12		
15	Well 15	05-30-06	1510	Deh Sabz										
16	Well 16	11-09-04	0000	Shomali	28	0.03	316	0.02	3.2	0.78	1.2	8		
17	Well 17	11-16-04	0000	Shomali	67	0.03	170	0.02	5.8	1.93	0.6	3		
18.2	Well 18.2	11-16-04	0000	Shomali	45	0.03	53	0.02	4.5	0.99	2.7	13		
20	Well 20	11-11-04	0000	Western Front	17	0.03	16	0.02	0.5	1.2	0.6	5		
20	Well 20	06-10-06	0925	Western Front										
21	Well 21	11-08-04	0000	Western Front	22	0.03	19	0.05	1	1.52	5	18		
21	Well 21	06-12-06	0920	Western Front										
22.1	Well 22.1	06-12-06	0945	Shomali										
23	Well 23	11-11-04	0000	Shomali	41	0.03	45	0.07	0.6	0.18	0.5	3		
24	Well 24	09-22-04	0000	Shomali	39	0.03	49	0.02	1.8	0.48	0.6	3.2		
24	Well 24	06-14-06	0950	Shomali										
25	Well 25	09-27-04	0000	Shomali	77	0.03	60	0.03	3.9	0.27	0.5	3.2		
25	Well 25	06-14-06	1015	Shomali										
26	Well 26	11-09-04	0000	Shomali	59	0.03	120	0.02	1.8	0.22	0.4	3		
27	Well 27	11-09-04	0000	Shomali	28	0.03	69	0.02	2.7	1.95	1.9	8		
28	Well 28	09-27-04	0000	Shomali	79	0.03	62	0.02	2.2	0.92	0.7	6.3		
28	Well 28	05-23-06	1300	Shomali	77		70	<0.05	2	0.25	0.5			<20
29	Well 29	11-01-04	0000	Shomali	63	0.03	229	0.02	0.4	0.46	3.8	20		
31.2	Well 31.2	10-30-04	0000	Shomali	85	0.03	127	0.02	2.6	1.58	0.8	6		
33	Well 33	10-30-04	0000	Western Front	42	0.03	35	0.03	0.5	1.28	1.2	3		
33	Well 33	05-23-06	1030	Western Front	46		30	<0.05	<1	0.3	0.4			<20
35	Well 35	11-07-04	0000	Deh Sabz	58	0.03	54	0.02	6.9	0.66	1.8	4		
36	Well 36	11-07-04	0000	Deh Sabz	37	0.03	114	0.02	9.8	1.32	1.1	9		
37	Well 37	11-07-04	0000	Deh Sabz	31	0.03	184	0.02	0.4	2.62	1.6	23		
37	Well 37	05-14-06	1000	Deh Sabz	34		170	<0.05	2	0.31	1.6			<20
38	Well 38	11-01-04	0000	Shomali	88	0.03	188	0.02	1	0.27	30.1	5		
39.2	Well 39.2	11-10-04	0000	Shomali	76	0.03	213	0.02	9.6	0.59	2.3	8		
41	Well 41	11-06-04	0000	Western Front	17	0.03	64	0.02	1.3	1.31	0.3	12		
41	Well 41	05-28-06	0950	Western Front										
42	Well 42	11-10-04	0000	Shomali	108	0.03	226	0.02	0.4	0.97	0.8	12		
42	Well 42	05-28-06	0810	Shomali	117		240	<0.05	5	0.42	0.8			<20
43	Well 43	05-28-06	0925	Western Front										
45	Well 45	11-08-04	0000	Western Front	204	0.03	328	0.02	5.1	0.29	0.5	3		
45	Well 45	05-30-06	1220	Western Front										
47	Well 47	05-30-06	1345	Shomali	123		850	<0.05	6	0.28	1.4			<20
52	Well 52	09-22-04	0000	Western Front	36	0.03	19	0.02	0.5	0.54	0.9	3.2		
52	Well 52	06-10-06	1030	Western Front										

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/day/ year)	Pb (µg/L)	Li (µg/L)	Mn ICPMS µg/L	Mn (µg/L)	Mo (µg/L)	Ni (µg/L)	Se (µg/L)	Ag (µg/L)	Sr (µg/L)	Th (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)	Comment
2.1	09-25-04	0.04	11.4	8.9	9.5	2.2	0.69	0.2	0.1	1,450	0.02	0.99	0.21	5.9	FAFU
2.1	06-07-06														
3	10-31-04	0.27	10.8	2.1	2.1	1.7	1.73	0.8	0.1	795	0.02	3.52	9.38	131	FAFU
6	05-10-06	19.4	6	9		2.1	0.9	2	<0.05	605		4.7	3.9	9	FAFU
7	10-31-04	0.04	6.8	0.8	0.7	2.2	2.47	0.4	0.1	730	0.02	4.47	2.66	1.2	FAFU
7	06-04-06														
8	11-02-04	0.36	159	3.8	3.2	1.7	0.4	5.4	0.1	3,810	0.02	21.4	7.41	903	FAFU
8	06-07-06														
9	09-25-04	0.38	14.5	2.9	3.1	0.9	1.01	1.7	0.1	807	0.02	3.46	7.32	241	FAFU
10	05-10-06	29.5	5	1		2.3	0.4	1	<0.05	811		8.4	1.6	14	FAFU
11	11-02-04	0.16	4.9	2.5	2.6	2.8	2.27	1	0.1	706	0.02	2.83	1.83	96.7	FAFU
12	11-18-04	0.04	124	3	3	5.3	3.54	12.7	0.1	7,090	0.02	22.3	5.59	8.7	FAFU
13	11-04-04	0.06	18.4	6.3	6	9.2	0.29	1.2	0.1	678	0.02	2.84	4.76	4.3	FAFU
13	05-16-06	0.09	15	2		8.5	0.4	2	<0.05	659		2.9	4.3	7	CFC,3H,FAFU
15	11-04-04	0.06	31.9	0.5	4.1	0.8	3.56	3.3	0.1	2,490	0.02	15.7	7.55	2.7	FAFU
15	05-30-06														
16	11-09-04	0.05	16.6	1.5	1.4	4.8	0.03	5.4	0.1	991	0.02	9.59	10	2.5	FAFU
17	11-16-04	0.04	17.5	5.9	5.6	2.4	0.2	0.5	0.1	1,040	0.02	4.91	3.75	2.1	FAFU
18.2	11-16-04	0.09	9.1	2.4	2.3	1	0.03	0.3	0.1	461	0.02	2.81	6.83	119	FAFU
20	11-11-04	0.04	1.4	4.7	4.4	0.7	0.1	0.2	0.1	299	0.02	1.93	3.15	4.5	FAFU
20	06-10-06														
21	11-08-04	0.06	3.9	7.4	7	0.3	0.23	0.2	0.1	199	0.02	1.5	4.64	412	FAFU
21	06-12-06														
22.1	06-12-06														
23	11-11-04	2.14	26	1.8	1.7	1.8	0.15	0.6	0.1	387	0.02	3.16	8.15	5090	FAFU
24	09-22-04	0.08	7.5	0.7	0.7	1	1.15	0.2	0.1	482	0.02	7.7	3.79	3.3	FAFU
24	06-14-06														
25	09-27-04	0.53	26	0.4	0.4	1	2.28	0.4	0.1	780	0.02	6.43	5.34	213	FAFU
25	06-14-06														
26	11-09-04	0.23	24.3	0.1	0.3	0.5	0.03	0.2	0.1	456	0.02	4.82	5.86	42.5	FAFU
27	11-09-04	0.25	17.5	4.3	4.1	0.8	0.29	0.3	0.1	220	0.02	1.59	8.97	2.8	FAFU
28	09-27-04	0.04	30.9	10.3	11	1.6	0.94	0.4	0.1	1,040	0.02	6.98	6.13	7.3	FAFU
28	05-23-06	0.11	24	1		2.5	0.6	<1	<0.05	972		7.5	6.6	19	CFC,3H,FAFU
29	11-01-04	0.04	17.9	12.3	12.1	3.3	1.24	3.5	0.1	1,920	0.02	14.7	5.91	5.5	FAFU
31.2	10-30-04	0.04	27.2	24.8	24	1	1.38	0.2	0.1	653	0.02	6.57	6.61	8.3	FAFU
33	10-30-04	0.73	15.4	12.8	12.1	1.2	0.27	0.3	0.1	476	0.02	2.83	4.8	271	FAFU
33	05-23-06	1.04	16	4		1.2	1.5	1	<0.05	517		4.1	4.9	540	CFC,3H,FAFU
35	11-07-04	0.93	6.3	1.2	1.1	1.8	0.45	1.6	0.1	681	0.02	2.95	4.49	107	FAFU
36	11-07-04	0.06	9.8	2	1.9	1.3	0.73	2.7	0.1	1,040	0.02	8.01	4.82	1.8	FAFU
37	11-07-04	0.17	18.9	18.2	17.6	3.8	1.2	1.8	0.1	928	0.02	8.17	6.9	190	FAFU
37	05-14-06	0.22	15	4		2.9	0.3	3	<0.05	805		6.4	11.3	8	CFC,3H,FAFU
38	11-01-04	0.21	55.6	2.1	2	2.5	0.9	0.6	0.1	910	0.02	11.3	3.49	339	FAFU
39.2	11-10-04	0.54	28	1.4	1.3	2.6	0.03	0.6	0.1	1,190	0.02	7.76	8.21	5.3	FAFU
41	11-06-04	0.04	15.7	4	3.9	0.7	0.73	0.3	0.1	157	0.02	2.26	4.42	1.1	FAFU
41	05-28-06														
42	11-10-04	0.04	33.2	33.4	31.3	1.6	0.29	0.3	0.1	968	0.02	7.12	5.24	3.2	FAFU
42	05-28-06	0.08	34	12		2.4	0.5	<1	<0.05	957		8.2	8.6	7	CFC,3H,FAFU
43	05-28-06														
45	11-08-04	0.31	72.1	0.4	0.3	0.8	10.8	0.4	0.1	1,390	0.02	8.55	6.14	2.1	FAFU
45	05-30-06														
47	05-30-06	0.19	103	<1		2.4	0.7	2.4	<0.05	2,120		17.8	5.7	12	CFC,3H,FAFU
52	09-22-04	0.04	4.7	2.9	3	0.4	0.81	0.2	0.1	307	0.02	1.73	4.03	9	FAFU
52	06-10-06														

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Sample water level (m)	Water tempe-rature (°C)	Spec. cond. (µS/cm)	Total dissolved solids (g/L)	pH field	O_2 (mgL)	NO_2 N field (mg/L)	NO_3 N field (mg/L)	Total coli count per 100 mL
53	Well 53	11-03-04	0000	Deh Sabz		14.4	803		7.31	7.1	0	3	200
54	Well 54	11-03-04	0000	Deh Sabz		17.1	1,224		7.74	9.1	0	1-2	1
54	Well 54	05-21-06	1145	Deh Sabz		18.2	1,204	0.55	7.59		0	2-5	2
56	Well 56	11-06-04	0000	Deh Sabz		15.6	542		7.75	8.3	0	1-2	1
58	Well 58	09-20-04	0000	Central Kabul	11.22	16.1	1,105		7.33	2.8	0	5	1
59.1	Well 59.1	11-16-04	0000	Eastern Front	34.99	16.7	614		7.75		0	1-2	2
59.1	Well 59.1	05-10-06	1005	Eastern Front	26.42	17.7	582	0.39	7.77		0	1-2	
60.1	Well 60.1	11-02-04	0000	Deh Sabz		17.4	488		7.59		0	3-5	101
63	Well 63	11-08-04	0000	Shomali	19	16.5	465		7.62	8.2	0	2	11
64	Well 64	06-24-06	0830	Central Kabul	7.12	16.9	1,156	0.56	7.28		0	2-5	1
65	Well 65	05-25-06	0930	Central Kabul	57.47	21.6	674	0.33	7.55		0	2-5	548
66.1	Spring 66.1	05-10-06	1110	Eastern Front		15.3	303	0.13	7.74		0	0-1	
67	Well 67	12-09-06	1300	Western Front	31.96	14.5	662	0.34	7.85		0	0-1	
67.1	Kheelre Spring	05-23-06	1145	Shomali		16.7	469	0.23	7.39		0	1-2	387
67.2	Spring 67A	06-17-06	1120	Shomali		18.6	2,199	1.23	5.78		0	0	
68.1	Spring 68	05-21-06	1000	Shomali		14.9	411	0.19	7.37		0	1-2	276
69.1	Karez 69.1	05-10-06	1030	Eastern Front		18.3	507	0.25	7.99		0	1-2	
71	Azizi Hotak Tank	06-05-07	0940	Eastern Front	35.84	20	754	0.34	8.02				
72	Well 72	06-12-07	0900	Shomali	24.94	15.2	524	0.23	8.02		0	1-2	
73	9 Pola Qare Bagh	06-17-07	1015	Western Front	23.2	16.3	295	0.12	8.44		0	0-1	
74	Well 74	06-19-07	1140	Shomali	27	15.2	1,144	0.45	7.54		0	0-1	
100	Swedish well 224	11-06-04	0000	Western Front		13.2	343.8		6.73		0	1-2	10
100	Swedish well 224	06-03-06	1100	Western Front	3.49	13.2	334	0.15	7.11		0	1-2	488
101	Spring 101	05-13-06	1130	Western Front		11	359	0.16	7.24		0	1-2	
102	Well 102	09-21-04	0000	Paghman/Upper Kabul	19.1	14.7	345		7.11	8.4	0	2-5	118
103	Well 103	09-21-04	0000	Paghman/Upper Kabul		12.9	392		7.16	9.6	0	2-5	1
104	Well 104	11-06-04	0000	Western Front		14.7	610		7.26		0	5-10	411
104	Well 104	05-13-06	1100	Western Front		14.4	761	0.45	7.52		0	20-50	
104	Well 104	12-03-06	1220	Western Front	17.21	12.1	1,000	0.37	7.78		0	20-50	
105	Karez 105	05-13-06	1000	Paghman/Upper Kabul		14.7	317	0.1	7.85		0	2	
106	Well 106	11-06-04	0000	Paghman/Upper Kabul		14.3	523		7.29		0	1-2	18
107	Well 107	11-06-04	0000	Paghman/Upper Kabul		15	533		7.36		0	1-2	1
107	Well 107	05-15-06	1040	Paghman/Upper Kabul		15.5	551	0.24	7.61		0	1-2	261
109	Well 109	11-08-04	0000	Paghman/Upper Kabul		13.3	532		7.65		0	1-5	4
110	Well 110	11-08-04	0000	Paghman/Upper Kabul	31.69	14.8	590		7.5		0-0.15	2-5	2
111	Well 111	11-09-04	0000	Paghman/Upper Kabul	6.1	12.7	540		7	0.36	0	2-5	200
112	Well 112	11-03-04	0000	Paghman/Upper Kabul		14.3	530		7.26		0	1-2	8
112	Well 112	06-03-06	1200	Paghman/Upper Kabul	10.44	16.2	530	0.25	7.68		0	1-2	11
113	Well 113	11-03-04	0000	Paghman/Upper Kabul		13.8	898		7.45		0	2-5	1
113	Well 113	05-29-06	0930	Paghman/Upper Kabul	5.97	15.4	960	0.45	7.55		0	1-2	68.9
114	Well 114	11-01-04	0000	Paghman/Upper Kabul		14.7	1,197		8.37		0	1-2	200
115	Well 115	11-01-04	0000	Paghman/Upper Kabul		17.3			7.33		1	10-20	78
115	Well 115	05-29-06	1015	Paghman/Upper Kabul	20.9	19.5	2,241	0.6	7.89		0	0	>2,420
116	Well 116	11-10-04	0000	Logar	5.9	14.4	1,084		7.32		0	2-5	200
116	Well 116	05-29-06	1105	Logar	2.51	15.9	1,475	0.74	7.49		0	2-5	>2,420
117	Well 117	11-01-04	0000	Paghman/Upper Kabul		14.3			7.57		0	1-2	3
117	Well 117	05-15-06	1220	Paghman/Upper Kabul	9.26	16.6	845	0.37	7.35		0	1-2	1

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month-day-year)	*E. coli* count per 100 mL	pH lab	Spec. cond. Lab (µS/cm)	NO_4 N (mg/L)	NO_2 N mg/L)	NO_2-NO_3N (mg/L)	NO_3 N (mg/L)	NO_3 NO_3 (mg/L)	Total N (mg/L)	PO_4 P (mg/L)	Ca (mg/L)	Mg (mg/L)	Hardness (mg/L)	Na (mg/L)
53	11-03-04	1				0.004	5					81	37.8	357.9	32.5
54	11-03-04	1				0.004	5.9					56	43.2	317.8	143
54	05-21-06	1						5.74	25.4			58.2	42.6	320.8	139
56	11-06-04	1				0.02	2.98	3	13.3			38	18.8	172.3	55.9
58	09-20-04	1	7.6	1120		0.004	8.52					60	78.1	471.5	74.8
59.1	11-16-04	1				0.004	0.64					42	27.7	219	39.5
59.1	05-10-06							1.02	4.51			46.4	28.8	234.5	48.6
60.1	11-02-04	1				0.01	3.25	3.2	14.2			52	26.1	237.3	26.7
63	11-08-04	1				0.004	2.44					51	19.9	209.3	17
64	06-24-06	1													
65	05-25-06	1						3.89	17.2			72.7	8.12	215	57.6
66.1	05-10-06							0.86	3.82			41.4	12.6	155.3	1.37
67	12-09-06		7.8	677										231.2	
67.1	05-23-06	7.4						2.42	10.7			61.9	14.2	213	18.6
67.2	06-17-06														
68.1	05-21-06	6.2						1.94	8.6			56.3	16.4	208.1	9.4
69.1	05-10-06							1.22	5.42			65.1	27.5	275.8	7.99
71	06-05-07			754				3.46	15.3			56.3	36.3		65.1
72	06-12-07			524				3.09	13.7			68	22.9		9.89
73	06-17-07			295				2.21	9.78			45	7.38		8.98
74	06-19-07			1144				2.37	10.5			108	39.3		63.6
100	11-06-04	1				0.004	1.77					52	7.2	159.5	7.2
100	06-03-06	1													
101	05-13-06							2.12	9.38			60.1	8.18	183.8	6.64
102	09-21-04	8	7.8	317		0.02	2.1	2.1	9.3			52	7	158.7	6.9
103	09-21-04	1	7.6	470		0.004	4.16					73	16.7	251.1	8.5
104	11-06-04	1				0.03	7.11	7.1	31.4			73	25.3	286.5	13
104	05-13-06							40.21	178			116.6	32.1	424.4	23.4
104	12-03-06		7.9	1000										419	
105	05-13-06							0.93	4.12			35.1	12.5	139.1	10.2
106	11-06-04	8				0.04	2.98	2.9	12.8			58	17.4	216.5	28.5
107	11-06-04	1				0.03	3.41	3.4	15.1			49	20.6	207.2	35.4
107	05-15-06	1						3.19	14.1			52.9	19.8	213.6	39.4
109	11-08-04	1				0.004	2.95					61	19.4	232.2	23.8
110	11-08-04	1				0.05	3.36	3.3	14.6			55	23.4	233.7	50.7
111	11-09-04	200				0.02	4.47	4.5	19.9			76	16.4	257.3	14.6
112	11-03-04	1				0.005	2.96	3	13.3			64	17	229.8	21.7
112	06-03-06	1													
113	11-03-04	1				0.01	4.56	4.6	20.4			83	45.4	394.2	59.6
113	05-29-06	1													
114	11-01-04	2				0.01	2.47	2.5	11.1			51	9.2	165.2	173
115	11-01-04	1				0.55	10.9	10.4	46			863	242	3151.6	565
115	05-29-06	13.4													
116	11-10-04	2				0.02	4.23	4.2	18.6			79	56.7	430.8	59.9
116	05-29-06	248													
117	11-01-04	1				0.008	2.5	2.5	11.1			73	33.3	319.4	26.5
117	05-15-06	1						3.16	14			91.1	42.4	402.1	29.9

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	SAR	K (mg/L)	Alk mg/L as $CaCO_3$ (D)	Alk mg/L as HCO_3 (R)	Alk mg/L as HCO_3 (R&D)	Alk mg/L as $CaCO_3$ R&D	sum meq cations	sum meq anions	Percent charge imbalance
53	Well 53	11-03-04	0000	Deh Sabz	0.75	3.7	238		290.2	238	8.79	6.42	7.79
54	Well 54	11-03-04	0000	Deh Sabz	3.49	4.2	222		270.7	222	12.83	12.43	0.78
54	Well 54	05-21-06	1145	Deh Sabz	3.38	4.4		268.6	268.6	220	12.72	12.40	0.63
56	Well 56	11-06-04	0000	Deh Sabz	1.85	2.5	244		297.5	244	6.01	5.90	0.44
58	Well 58	09-20-04	0000	Central Kabul	1.5	5.5	380		463.3	380	13.09	7.60	13.28
59.1	Well 59.1	11-16-04	0000	Eastern Front	1.16	3.2	208		253.6	208	6.27	6.09	0.73
59.1	Well 59.1	05-10-06	1005	Eastern Front	1.38	2.9		254.3	254.3	209	6.98	6.76	0.78
60.1	Well 60.1	11-02-04	0000	Deh Sabz	0.75	1.5	161		196.3	161	6.03	5.47	2.46
63	Well 63	11-08-04	0000	Shomali	0.51	2.1	231		281.7	231	5.05	4.95	0.48
64	Well 64	06-24-06	0830	Central Kabul									
65	Well 65	05-25-06	0930	Central Kabul	1.71	7.7		154.8	154.8	127	7.03	6.68	1.28
66.1	Spring 66.1	05-10-06	1110	Eastern Front	0.05	0.7		176.2	176.2	145	3.22	3.24	-0.10
67	Well 67	12-09-06	1300	Western Front	1.1		213		259.7	213			
67.1	Kheelre Spring	05-23-06	1145	Shomali	0.55	3.6		280.0	280.0	230	5.21	4.84	1.85
67.2	Spring 67A	06-17-06	1120	Shomali									
68.1	Spring 68	05-21-06	1000	Shomali	0.28	3.5		244.9	244.9	201	4.72	4.38	1.86
69.1	Karez 69.1	05-10-06	1030	Eastern Front	0.21	1.3		320.0	320.0	262	5.99	5.90	0.38
71	Azizi Hotak Tank	06-05-07	0940	Eastern Front		2.2		310.6	310.6	255	8.81	8.83	-0.04
72	Well 72	06-12-07	0900	Shomali		2.7		327.0	327.0	268	5.86	5.68	0.76
73	9 Pola Qare Bagh	06-17-07	1015	Western Front		3.2		180.8	180.8	148	3.35	3.13	1.71
74	Well 74	06-19-07	1140	Shomali		13		362.3	362.3	297	11.86	11.34	1.13
100	Swedish well 224	11-06-04	0000	Western Front	0.25	2	160		195.1	160	3.58	3.52	0.43
100	Swedish well 224	06-03-06	1100	Western Front									
101	Spring 101	05-13-06	1130	Western Front	0.21	2.5		218.9	218.9	180	4.05	3.94	0.73
102	Well 102	09-21-04	0000	Paghman/Upper Kabul	0.24	1.7	158		192.6	158	3.54	3.16	2.83
103	Well 103	09-21-04	0000	Paghman/Upper Kabul	0.23	3	182		221.9	182	5.52	3.64	10.27
104	Well 104	11-06-04	0000	Western Front	0.33	1.6	217		264.6	217	6.42	5.12	5.63
104	Well 104	05-13-06	1100	Western Front	0.49	1.2		263.6	263.6	216	9.62	6.64	9.15
104	Well 104	12-03-06	1220	Western Front	0.43		210		256.0	210			
105	Karez 105	05-13-06	1000	Paghman/Upper Kabul	0.38	1.6		180.0	180.0	148	3.31	3.28	0.23
106	Well 106	11-06-04	0000	Paghman/Upper Kabul	0.84	3.7	223		271.9	223	5.72	5.31	1.86
107	Well 107	11-06-04	0000	Paghman/Upper Kabul	1.07	2.9	238		290.2	238	5.83	5.45	1.68
107	Well 107	05-15-06	1040	Paghman/Upper Kabul	1.17	3		312.1	312.1	256	6.13	5.79	1.41
109	Well 109	11-08-04	0000	Paghman/Upper Kabul	0.68	2.3	255		310.9	255	5.80	5.74	0.28
110	Well 110	11-08-04	0000	Paghman/Upper Kabul	1.44	5.9	270		329.2	270	7.11	6.55	2.04
111	Well 111	11-09-04	0000	Paghman/Upper Kabul	0.4	2.7	193		235.3	193	5.90	4.64	6.01
112	Well 112	11-03-04	0000	Paghman/Upper Kabul	0.62	2.8	244		297.5	244	5.67	5.57	0.45
112	Well 112	06-03-06	1200	Paghman/Upper Kabul									
113	Well 113	11-03-04	0000	Paghman/Upper Kabul	1.31	4.3	302		368.2	302	10.74	9.68	2.60
113	Well 113	05-29-06	0930	Paghman/Upper Kabul									
114	Well 114	11-01-04	0000	Paghman/Upper Kabul	5.86	4.3	84		102.4	84	10.97	10.86	0.26
115	Well 115	11-01-04	0000	Paghman/Upper Kabul	4.38	15.5	104		126.8	104	88.80	2.08	47.71
115	Well 115	05-29-06	1015	Paghman/Upper Kabul									
116	Well 116	11-10-04	0000	Logar	1.26	4.7	300		365.8	300	11.53	11.08	1.00
116	Well 116	05-29-06	1105	Logar									
117	Well 117	11-01-04	0000	Paghman/Upper Kabul	0.65	4.5	224		273.1	224	7.77	5.63	8.00
117	Well 117	05-15-06	1220	Paghman/Upper Kabul	0.65	4.7		485.9	485.9	399	9.61	9.36	0.64

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Cl (mg/L)	SO_4 (mg/L)	F (mg/L)	Br (mg/L)	SiO_2 (mg/L)	ROE	SOC	ROESOC	Ion Balance Charge	Ion Balance Percent	ROESC	Al (µg/L)	Sb (µg/L)	As (µg/L)	As (µg/L) (R or D)
53	11-03-04	18	55.6	0.37		29	403					0.5	0.9	0.1		1.2
54	11-03-04	69.3	290	0.58	0.39	39	814					0.67	1.1	0.1		3.8
54	05-21-06	67.9	292	0.62	0.29	41.1		833		-1.21	-4.6		1	<0.1	4.4	4.4
56	11-06-04	5.5	41.7	1.08	0.08	35	346	358	0.97	-0.17	-1.45	0.64	0.8	0.1		1.9
58	09-20-04		0.09	0.31	0.22	33	689					0.62	1.2	0.1		2.5
59.1	11-16-04	17.8	68.8	0.26	0.12	19	345					0.56	2.8	0.3		2.1
59.1	05-10-06	23.7	92.3	0.3	0.11	17.4		417		-0.87	-5.92		3	0.2	2.5	2.5
60.1	11-02-04	28.6	69.3	0.2	0.23	18	346	333	1.04	0.25	2.12	0.71	0.9	0.1		0.8
63	11-08-04	4.4	10	0.25	0.06	22	271					0.58	1.5	0.1		1.2
64	06-24-06															
65	05-25-06	21.9	169	1.61	0.09	27.0		476		-0.51	-3.54		3	<0.1	0.6	0.6
66.1	05-10-06	1.65	14.5	0.19	<0.05	6.3				-0.75	-10.51		10	<0.1	0.4	0.4
67	12-09-06						385					0.58				0.5
67.1	05-23-06	3.63	6.92	0.28	<0.05	25.2				-0.86	-7.66		1	<0.1	0.5	0.5
67.2	06-17-06															
68.1	05-21-06	7.24	7.6	0.24	<0.05	22.7				-0.74	-7.35		1	0.2	1.9	1.9
69.1	05-10-06	3.78	26.2	0.3	<0.05	17.3				-1.24	-9.53		825	<0.1	0.9	0.9
71	06-05-07	29	140	0.2	0.16	19.0							5	<0.1	1.3	1.3
72	06-12-07	5.75	7.63	0.18	<0.05	24.7							7	<0.1	0.8	0.8
73	06-17-07	2.66	4.33	0.11	<0.05	19.2							7	<0.1	0.6	0.6
74	06-19-07	119	98	0.11	0.17	15.9							5	0.1	0.3	0.3
100	11-06-04	5	8.5	0.1	0.05	19	199					0.58	0.8	0.1		0.5
100	06-03-06															
101	05-13-06	5.69	9	0.22	<0.05	17.6				-0.85	-9.56		<1	0.1	1.1	1.1
102	09-21-04		0.09	0.09	0.02	15	206					0.6	3.7	0.1		0.3
103	09-21-04		0.09	0.2	0.04	20							2	0.1		1
104	11-06-04	19.9	10.7	0.3	0.07	31	339	336	1.01	0.7	5.89	0.56	3.4	0.1		0.4
104	05-13-06	64.8	23.8	0.59	0.07	27.4		627		-0.94	-4.7		1	<0.1	0.4	0.4
104	12-03-06						617					0.62				0.4
105	05-13-06	3.64	10.8	0.36	<0.05	18.5				-0.73	-10.01		2	0.1	2.2	2.2
106	11-06-04	10.3	27	0.33	0.08	21	314	313	1	0.14	1.29	0.6	1.6	0.1		2.4
107	11-06-04	6.3	24.6	0.5	0.1	26	318	323	0.98	0.07	0.57	0.6	1.8	0.1		2.2
107	05-15-06	6.24	24.1	0.57	0.05	26.1		373		-1.08	-8.19		1	0.1	3	3
109	11-08-04	8.2	19.7	0.25	0.11	20	313					0.59	1.6	0.1		0.9
110	11-08-04	12.1	39.1	0.31		30	393			0.24	1.74	0.67	1,570	0.2		0.3
111	11-09-04	13.3	19.4	0.14		19	305			0.89	8.23	0.56	3.9	0.1		1.1
112	11-03-04	10.8	18.5	0.17	0.08	20	310	315	0.98	-0.17	-1.51	0.58	1.6	0.1		1.2
112	06-03-06															
113	11-03-04	74.9	73.4	0.29	0.22	28	586	571	1.03	0.58	2.8	0.65	2.4	0.3		0.4
113	05-29-06															
114	11-01-04	205	163	0.11	0.64	13	696	681	1.02	-0.1	-0.44	0.58	2.1	0.1		0.7
115	11-01-04			0.09		17	5330						305	0.2		7.1
115	05-29-06															
116	11-10-04	129	69.5	0.29	0.24	27	611	625	0.98	-0.05	-0.2	0.56	2.4	0.3		0.3
116	05-29-06															
117	11-01-04	22	25.3	0.22	0.1	18	353	348	1.01	1.85	13.74		1.7	0.1		0.6
117	05-15-06	28.6	28.4	0.24	0.06	21.1		552		-1.88	-9.04		1	<0.1	0.8	0.8

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Ba (µg/L)	Be (µg/L)	B (µg/L)	Cd (µg/L)	Cr (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L) D	Fe (µg/L)
53	Well 53	11-03-04	0000	Deh Sabz	75	0.03	182	0.02	5.6	0.87	1.5	12	
54	Well 54	11-03-04	0000	Deh Sabz	15	0.03	451	0.02	9.1	0.61	2.7	3	
54	Well 54	05-21-06	1145	Deh Sabz	16		420	<0.05	9	0.35	2.5		<20
56	Well 56	11-06-04	0000	Deh Sabz	43	0.03	230	0.03	4.5	0.87	2	5	
58	Well 58	09-20-04	0000	Central Kabul	79	0.03	880	0.02	0.4	0.91	1.2	5.5	
59.1	Well 59.1	11-16-04	0000	Eastern Front	79	0.03	88	0.02	1.6	3.52	0.8	6	
59.1	Well 59.1	05-10-06	1005	Eastern Front	69		100	<0.05	2	0.16	0.69		<20
60.1	Well 60.1	11-02-04	0000	Deh Sabz	61	0.03	52	0.02	3.4	1.12	0.7	13	
63	Well 63	11-08-04	0000	Shomali	72	0.03	152	0.02	8.7	1.41	1.6	20	
64	Well 64	06-24-06	0830	Central Kabul									
65	Well 65	05-25-06	0930	Central Kabul	18		140	<0.05	<1	1.2	1.2		<20
66.1	Spring 66.1	05-10-06	1110	Eastern Front	8		20	<0.05	<1	0.06	0.3		<20
67	Well 67	12-09-06	1300	Western Front		0.06							
67.1	Kheelre Spring	05-23-06	1145	Shomali	48		40	<0.05	<1	0.3	0.3		<20
67.2	Spring 67A	06-17-06	1120	Shomali									
68.1	Spring 68	05-21-06	1000	Shomali	28		40	<0.05	1	0.22	0.35		<20
69.1	Karez 69.1	05-10-06	1030	Eastern Front	44		50	<0.05	2	0.5	1.2		720
71	Azizi Hotak Tank	06-05-07	0940	Eastern Front	31		150	<0.05	9	0.09	1.4		<20
72	Well 72	06-12-07	0900	Shomali	40		40	<0.05	8	0.11	0.7		20
73	9 Pola Qare Bagh	06-17-07	1015	Western Front	40		20	<0.05	4	0.07	0.5		<20
74	Well 74	06-19-07	1140	Shomali	74		1,420	<0.05	3	0.27	1.7		40
100	Swedish well 224	11-06-04	0000	Western Front	16	0.03	22	0.02	0.5	0.54	10.2	26	
100	Swedish well 224	06-03-06	1100	Western Front									
101	Spring 101	05-13-06	1130	Western Front	29		20	<0.05	1	0.39	0.6		<20
102	Well 102	09-21-04	0000	Paghman/Upper Kabul	13	0.03	35	0.02	0.4	0.44	0.7	3.2	
103	Well 103	09-21-04	0000	Paghman/Upper Kabul	27	0.03	42	0.02	2.1	0.4	1	4.7	
104	Well 104	11-06-04	0000	Western Front	13	0.03	64	0.02	2.4	1.41	0.5	12	
104	Well 104	05-13-06	1100	Western Front	21		50	<0.05	<1	0.49	6.3		<20
104	Well 104	12-03-06	1220	Western Front		0.06							
105	Karez 105	05-13-06	1000	Paghman/Upper Kabul	14		60	<0.05	<1	0.37	0.6		<20
106	Well 106	11-06-04	0000	Paghman/Upper Kabul	28	0.03	216	0.02	5.3	0.23	0.7	5	
107	Well 107	11-06-04	0000	Paghman/Upper Kabul	28	0.03	192	0.03	5.2	1.8	6.2	9	
107	Well 107	05-15-06	1040	Paghman/Upper Kabul	29		190	<0.05	7	0.31	1.8		<20
109	Well 109	11-08-04	0000	Paghman/Upper Kabul	32	0.03	119	0.23	2.1	2.29	1.5	7	
110	Well 110	11-08-04	0000	Paghman/Upper Kabul	86	0.05	862	0.02	7.8	1.38	14.2	1,690	
111	Well 111	11-09-04	0000	Paghman/Upper Kabul	20	0.03	73	0.02	2.1	1.36	0.7	6	
112	Well 112	11-03-04	0000	Paghman/Upper Kabul	17	0.03	109	0.02	2.4	1.47	4.2	11	
112	Well 112	06-03-06	1200	Paghman/Upper Kabul									
113	Well 113	11-03-04	0000	Paghman/Upper Kabul	85	0.03	921	0.02	0.4	0.34	0.9	7	
113	Well 113	05-29-06	0930	Paghman/Upper Kabul									
114	Well 114	11-01-04	0000	Paghman/Upper Kabul	39	0.03	109	0.02	1.8	0.49	1.2	10	
115	Well 115	11-01-04	0000	Paghman/Upper Kabul	90	0.05	357	0.06	1.1	6.72	7.1	265	
115	Well 115	05-29-06	1015	Paghman/Upper Kabul									
116	Well 116	11-10-04	0000	Logar	80	0.03	1,260	0.02	3.8	2.94	1.4	6	
116	Well 116	05-29-06	1105	Logar									
117	Well 117	11-01-04	0000	Paghman/Upper Kabul	64	0.03	528	0.02	0.4	0.8	0.9	13	
117	Well 117	05-15-06	1220	Paghman/Upper Kabul	97		610	<0.05	<1	0.22	2.6		<20

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Pb (µg/L)	Li (µg/L)	Mn ICPMS µg/L	Mn (µg/L)	Mo (µg/L)	Ni (µg/L)	Se (µg/L)	Ag (µg/L)	Sr (µg/L)	Th (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)	Comment
53	11-03-04	0.14	21.6	3.7	3.7	1.7	0.03	0.8	0.1	1,180	0.02	8.85	5.87	3.6	FAFU
54	11-03-04	0.16	23.5	0.8	0.7	4.6	0.03	5.1	0.1	1,270	0.02	10.4	14.5	141	FAFU
54	05-21-06	1.9	21	<1		4.7	4.5	7	<0.05	1,310		11.6	14.2	48	CFC,3H,FAFU
56	11-06-04	0.2	12.7	1.4	1.3	11.4	0.11	1.1	0.1	816	0.02	17.3	17.5	68.5	FAFU
58	09-20-04	0.04	184	1.2	1.1	2.5	6.88	1.4	0.1	1,020	0.02	7.56	1.89	2.5	FAFU
59.1	11-16-04	0.15	10.7	6.2	6.1	2.8	1.54	0.9	0.1	764	0.02	4.84	7.97	91.8	FAFU
59.1	05-10-06	16.1	8	<1		3.7	0.6	2	<0.05	858		9.2	1.7	84	CFC,3H,FAFU
60.1	11-02-04	0.08	5.4	3.4	3.4	1.5	0.63	1.9	0.1	488	0.02	3.47	3.53	1.3	FAFU
63	11-08-04	0.37	15.6	2.4	2.3	1.8	0.03	0.7	0.1	665	0.02	4.6	5.89	143	FAFU
64	06-24-06														
65	05-25-06	0.38	17	<1		6.7	0.8	1	<0.05	629		2.6	10.5	388	CFC,3H,FAFU
66.1	05-10-06	2.95	<1	<1		3	<0.1	<1	<0.05	293		2.7	0.5	4	CFC,3H,FAFU
67	12-09-06								0.1		0.04				3H,FAFU
67.1	05-23-06	0.57	25	<1		2.2	0.3	<1	<0.05	396		4.4	16.1	8	CFC,3H,FAFU
67.2	06-17-06														
68.1	05-21-06	7.12	7	<1		4	0.1	<1	<0.05	339		2.6	4.8	12	CFC,3H,FAFU
69.1	05-10-06	0.7	7	21		2.6	1.9	<1	<0.05	659		5.3	4.1	3	FAFU
71	06-05-07	0.38	15	<1		1.8	1	3	<0.05	978		6.02	6.7	134	CFC,3H,FAFU,DG, NFA
72	06-12-07	0.3	16	<1		1	0.4	<1	<0.05	559		3.71	7.5	12	CFC,3H,FAFU,DG, NFA
73	06-17-07	0.14	8	<1		1.4	0.2	<1	<0.05	219		2.02	9.7	4	CFC,3H,FAFU,DG, NFA
74	06-19-07	0.13	329	17		0.6	0.9	1	<0.05	831		4.51	1.6	165	CFC,3H,FAFU,DG
100	11-06-04	0.25	3	1.3	1.3	0.5	0.59	0.2	0.1	196	0.02	0.89	2.45	44.8	FAFU
100	06-03-06														
101	05-13-06	0.44	5	<1		2.1	0.2	<1	<0.05	284		1.3	6.5	2	CFC,3H,FAFU
102	09-21-04	0.04	3.1	1.1	1.2	0.5	0.74	0.2	0.1	216	0.02	0.98	1.57	4.4	FAFU
103	09-21-04	0.04	4.9	0.8	0.8	1.2	0.73	0.2	0.1	554	0.02	2.71	2.35	0.7	FAFU
104	11-06-04	0.04	2.7	13.1	12.4	0.5	1.04	0.3	0.1	893	0.02	3.23	3.29	3.9	FAFU
104	05-13-06	2	4	1		0.5	1.1	<1	<0.05	1,600		5.3	2.4	207	CFC,3H,FAFU
104	12-03-06								0.1		0.04				3H,FAFU
105	05-13-06	0.32	6	3		3	0.1	<1	<0.05	463		2.2	1.9	3	CFC,3H,FAFU
106	11-06-04	0.08	51.8	0.3	0.3	4.7	0.64	0.8	0.1	431	0.02	5.35	4.55	1.1	FAFU
107	11-06-04	0.29	35.4	13.4	13	4.2	1.1	0.9	0.1	470	0.02	4.37	8.46	3.9	FAFU
107	05-15-06	4	33	1		4.4	0.2	1	<0.05	457		8.2	9.5	6	CFC,3H,FAFU
109	11-08-04	0.75	10.1	4.3	3.8	1.5	2.18	0.3	0.1	566	0.02	3.9	2.36	204	FAFU
110	11-08-04	2.02	62.9	12.6	51.1	1.2	5.43	0.5	0.1	136	0.02	4.52	10	71.2	FAFU
111	11-09-04	0.07	6.9	2.7	2.6	0.8	1	0.7	0.1	383	0.02	4.47	2.5	4.6	FAFU
112	11-03-04	0.08	10.6	3.3	3.2	1	1.03	0.8	0.1	414	0.02	3.9	2.21	74.9	FAFU
112	06-03-06														
113	11-03-04	0.13	121	0.1	0.3	1.7	14.2	0.3	0.1	373	0.02	6.44	0.87	6.8	FAFU
113	05-29-06														
114	11-01-04	0.07	32.4	1.8	1.9	1	1.04	2.7	0.1	1,400	0.02	5.77	5.35	97.4	FAFU
115	11-01-04	13.1	147	1,070	1,130	1.6	11.2	91.1	0.1	22,300	0.02	12.9	0.9	1950	FAFU
115	05-29-06														
116	11-10-04	0.15	163	1.3	5.1	1.5	3.11	0.2	0.1	2,490	0.02	11.5	6.2	5.6	FAFU
116	05-29-06														
117	11-01-04	0.23	77.8	12.8	12.3	1.6	8.16	0.7	0.1	651	0.02	2.74	0.77	445	FAFU
117	05-15-06	0.62	87	2		1.2	10.4	1	<0.05	784		3.4	1.7	511	CFC,3H,FAFU

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Sample water level (m)	Water tempe-rature (°C)	Spec. cond. (µS/cm)	Total dissolved solids	pH field	O_2 (mgL)	NO_2 N field (mg/L)	NO_3 N field (mg/L)	Total coli count per 100 mL
118	Well 118	11-01-04	0000	Paghman/Upper Kabul		13.3	922		7.54		0	1	1
119	Well 119	11-03-04	0000	Paghman/Upper Kabul		13.9	951		6.96		0	2-5	74
120	Well 120	11-08-04	0000	Paghman/Upper Kabul		14.4	656		7.39		0	1-5	1
121	Well 121	11-08-04	0000	Paghman/Upper Kabul		13.9	756		7.37		0	2-5	1
124	Well 124	05-27-06	0900	Central Kabul	4.9	14.5	820	0.4	7.57		0	1-2	1
125	Well 125	11-22-04	0000	Central Kabul		15.8	3,420		7.2	12.9	0	10	1,203
126	Well 126	11-22-04	0000	Central Kabul	10.83	14.8	1,056		7.23	6.3	0	2-5	1
129	Well 129	05-24-06	1255	Central Kabul	10.11	17.6	1,177	0.5	7.41		0	2-5	147
130	Well 130	11-03-04	0000	Paghman/Upper Kabul		15.6	909		7.29		0	2-5	5
131	Well 131	09-23-04	0000	Central Kabul	10.65	15.5	844		7.77	8.6	0	1-5	2
132	Well 132	11-22-04	0000	Central Kabul	20.07	15.9	2,760		7.01		0.15	50	2
133	Well 133	11-22-04	0000	Central Kabul	6.84	13.1	1,471		7.83		0	2-5	219
133	Well 133	05-27-06	0930	Central Kabul	4.33	16.2	1,740	0.87	7.51		0	1-2	1
134	Well 134	11-22-04	0000	Logar	7.44	16	1,678		7.79		0	5-10	488
135	Well 135	11-10-04	0000	Logar	12.15	14.3	1,398		7.23		0	2-5	200
135	Well 135	05-17-06	1050	Logar	6.43	15.3	1,343	0.58	7.42		0	2-5	183
136	Well 136	11-10-04	0000	Logar	9.4	13.7	1,084		7.52		0	2-5	36
138	Well 138	11-10-04	0000	Logar	10.78	14.2	1,320		7.48		0	2-5	3
139	Well 139	11-16-04	0000	Logar	10.13	14	1,436		7.31		0	1-2	200
140	Well 140	11-16-04	0000	Logar	10.2	14.5	1,360		7.32		0	2-5	1
140	Well 140	05-29-06	1220	Logar	10.7	15.8	1,391	0.61	7.54		0	1-2	34.5
141	Well 141	11-18-04	0000	Logar	6.5	15.6	1,992		7.67	3.4	0	2	1
143	Well 143	11-16-04	0000	Logar	9.3	14.3	1,435		7.56		0	2-5	200
143	Well 143	05-29-06	1200	Logar	6.38	14.5	1,595	0.88	7.64		0	1-2	>2,420
147	Well 147	11-11-04	0000	Central Kabul		15.7	672		7.75		0	2-5	144
148	Well 148	09-26-04	0000	Central Kabul	11.03	18.3	1,887		7.44	4.6	0	5	50
148	Well 148	06-05-06	1015	Central Kabul	11.55	18.1	2,099	0.92	7.64		0	2-5	83.9
150	Well 150	10-31-04	0000	Central Kabul		16.6	413		8.99	6.3	0	0-1	200
151	Well 151	10-31-04	0000	Central Kabul		16.4	1,857		7.76	2.3	0	2	8
152	Well 152	11-11-04	0000	Central Kabul	15.95	16	722		7.72		0	1-2	19
152	Well 152	06-05-06	1000	Central Kabul	15.9	16.6	758	0.36	7.85		0	1-2	138
153	Well 153	11-11-04	0000	Central Kabul	11.4	17.8	15,290		7.55		0.15	2-5	200
153	Well 153	11-17-04	0000	Central Kabul	8	17.3	14,010		7.81	2.7	0.15	2-5	517
153	Well 153	05-20-06	1305	Central Kabul		20	7,350	3.7	8.25		0.15-0.3	2-5	>2,420
154	Well 154	11-11-04	0000	Central Kabul		14.6	1,415		7.76		0	1-2	12
156	Well 156	11-20-04	0000	Central Kabul	5.95	15.6	1,943		7.39		0.15	20	161
156	Well 156	05-27-06	1000	Central Kabul	3.06	15.3	2,063	1.04	7.93		0	0-1	365
157	Well 157	11-20-04	0000	Central Kabul	6.6	18.2	4,941		7.56	5.3	0.15-0.3	50	24
157	Well 157	05-27-06	1010	Central Kabul	4.95	18	5,570	2.82	7.53		0	20-50	>2,420
159	Well 159	11-20-04	0000	Logar	4.9	11.9	1,428		7.82	10.9	0	0	20
160	Well 160	11-17-04	0000	Central Kabul	6.78	13.8	1,479		7.63	2.1	0	2-5	109
162.2	Well 162.2	05-31-06	1020	Central Kabul	7.1	16.6	1,476	0.75	7.62		0	1-2	1
163	Well 163	11-17-04	0000	Central Kabul	8.6	14.1	1,165		7.8	7.8	0	2-5	>2,420
163	Well 163	05-31-06	1040	Central Kabul	5.8	16.1	1,326	0.62	7.73		0	1-2	>2,420
164	Well 164	11-21-04	0000	Central Kabul	12	15.2	1,389		7.49	5.5	0	10-20	1
165	Well 165	11-21-04	0000	Central Kabul	20.51	13.3	1,002		7.68	2.6	0	5	1
165	Well 165	05-22-06	1000	Central Kabul	19.2	16.2	525	0.59	7.54		0	2-5	1,414
166.2	Well 166.2	11-21-04	0000	Central Kabul	7	17	12,000		7.65	2.2	0	0-1	1
167	Well 167	11-02-04	0000	Central Kabul	16.65	16.4	1,517		7.67	8.5	0	2-5	10
167	Well 167	06-20-06	0945	Central Kabul	17.67	20.4	1,465	0.71	7.85		0	2-5	4.1
168	Well 168	11-02-04	0000	Central Kabul	10.73	16.1	1,385		7.62	3.9	0	10-20	200
168	Well 168	05-22-06	1040	Central Kabul	11.2	18.4	1,532	0.74	7.41		0.3	50	325
169.2	Well 169.2	11-04-04	0000	Central Kabul		16.6	962		7.1	6.9	0	2-5	1

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month-day-year)	*E. coli* count per 100 mL	pH lab	Spec. cond. Lab (µS/cm)	NO_4 N (mg/L)	NO_2 N mg/L)	NO_2-NO_3N (mg/L)	NO_3 N (mg/L)	NO_3 NO_3 (mg/L)	Total N (mg/L)	PO_4 P (mg/L)	Ca (mg/L)	Mg (mg/L)	Hardness (mg/L)	Na (mg/L)
118	11-01-04	1				0.004	2.3					81	41.4	372.8	48.9
119	11-03-04	2				0.02	3.72	3.7	16.4			89	46.2	412.5	46.1
120	11-08-04	1				0.004	3.37					65	24.5	263.2	41.2
121	11-08-04	1				0.004	3.37	3.4	15.1			59	31.6	277.5	64.4
124	05-27-06	1													
125	11-22-04	1				0.007	24	24	106.2			137	104	770.4	368
126	11-22-04	1				0.007	8.46	8.5	37.6			84	54.7	435	60.7
129	05-24-06	4.1						13.46	59.6			91.3	62.3	484.6	74.9
130	11-03-04	1				0.004	15.6	15.6	69.1			82	48.7	405.3	68.9
131	09-23-04	1	7.8	780		0.004	3.93					68	43	346.9	46
132	11-22-04	1				0.004	144					264	109	1108.1	107
133	11-22-04	1				0.01	3.89	3.9	17.3			70	77.7	494.8	109
133	05-27-06	1													
134	11-22-04	1				0.06	11.3	11.2	49.6			48	127	642.9	133
135	11-10-04	1				0.07	6.39	6.3	27.9			63	96.2	553.5	102
135	05-17-06	1						8.92	39.5			70.8	87.9	538.8	96.5
136	11-10-04	1				0.03	1.14	1.1	4.9			43	68.6	389.9	80.3
138	11-10-04	1				0.009	3.65	3.6	15.9			43	100	519.2	95.6
139	11-16-04	165				0.01	0.75	0.7	3.1			67	105	599.7	105
140	11-16-04	1				0.006	3.75	3.7	16.4			66	93.9	551.5	99.8
140	05-29-06	1													
141	11-18-04	1				0.004	3.62					41	142	687.2	188
143	11-16-04	1				0.06	4.99	4.9	21.7			53	104	560.7	110
143	05-29-06	22													
147	11-11-04	6				0.004	2.71					55	34.2	278.2	34.7
148	09-26-04	1	7.7	2010		0.05	7.85	7.8	34.5			95	94.3	625.6	219
148	06-05-06	1													
150	10-31-04	1				0.004	0.03					8.23	3.34	34.3	86.8
151	10-31-04	1				0.01	1.65	1.6	7.1			81	103	626.5	175
152	11-11-04	1				0.004	2.66					56	35.1	284.4	41.3
152	06-05-06	1													
153	11-11-04	1				0.05	1.98	1.9	8.4			281	481	2682.7	2,570
153	11-17-04	1				0.19	1.92	1.7	7.5			223	427	2315.4	2,300
153	05-20-06	1						0.96	4.23			56.6	269	1249.2	1,230
154	11-11-04	1				0.01	2.28	2.3	10.2			39	104	525.7	116
156	11-20-04	6				0.18	16.6	16.4	72.6			114	120	778.9	128
156	05-27-06	5.2													
157	11-20-04	1				0.24	35.6	35.4	156.7			152	255	1429.8	591
157	05-27-06	1													
159	11-20-04	1				0.004	0.03					38.6	114	565.9	102
160	11-17-04	3				0.004	3.92					52	108	574.6	109
162.2	05-31-06	1													
163	11-17-04	6				0.04	4.95	4.9	21.7			64	71.9	455.9	89.4
163	05-31-06	461													
164	11-21-04	1				0.004	15.8					79	112	658.5	154
165	11-21-04	1				0.16	9.31	9.2	40.7			55	62	392.7	58.5
165	05-22-06	1						10.57	46.8			57.3	69.3	428.5	66.2
166.2	11-21-04	1				0.004	0.26					334	590	3263.9	1,630
167	11-02-04	1				0.006	12.9	12.9	57.1			92	68.5	511.8	138
167	06-20-06	1													
168	11-02-04	1				0.004	29.5					85	65.7	482.8	114
168	05-22-06	1						27.11	120			88.2	66.4	493.7	114
169.2	11-04-04	1				0.004	5.64					68	50.2	376.5	61.1

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	SAR	K (mg/L)	Alk mg/L as $CaCO_3$ (D)	Alk mg/L as HCO_3 (R)	Alk mg/L as HCO_3 (R&D)	Alk mg/L as $CaCO_3$ R&D	sum meq cations	sum meq anions	Percent charge imbalance
118	Well 118	11-01-04	0000	Paghman/Upper Kabul	1.1	5	254		309.7	254	9.85	7.83	5.71
119	Well 119	11-03-04	0000	Paghman/Upper Kabul	0.99	4.7	312		380.4	312	10.53	9.21	3.35
120	Well 120	11-08-04	0000	Paghman/Upper Kabul	1.11	4.3	290		353.6	290	7.25	7.03	0.77
121	Well 121	11-08-04	0000	Paghman/Upper Kabul	1.68	2	353		430.4	353	8.51	8.41	0.28
124	Well 124	05-27-06	0900	Central Kabul									
125	Well 125	11-22-04	0000	Central Kabul	5.77	18.4	377		459.7	377	32.24	29.28	2.41
126	Well 126	11-22-04	0000	Central Kabul	1.27	8.7	328		399.9	328	11.75	9.80	4.51
129	Well 129	05-24-06	1255	Central Kabul	1.48	8.9		510.0	510.0	418	13.39	12.32	2.07
130	Well 130	11-03-04	0000	Paghman/Upper Kabul	1.49	7.4	304		370.7	304	11.46	10.35	2.55
131	Well 131	09-23-04	0000	Central Kabul	1.07	5.1	334		407.2	334	9.21	9.16	0.15
132	Well 132	11-22-04	0000	Central Kabul	1.4	12.5	226		275.6	226	27.50	16.29	12.80
133	Well 133	11-22-04	0000	Central Kabul	2.13	54.9	487		593.8	487	16.31	15.79	0.81
133	Well 133	05-27-06	0930	Central Kabul									
134	Well 134	11-22-04	0000	Logar	2.28	7.5	477		581.6	477	19.27	17.86	1.90
135	Well 135	11-10-04	0000	Logar	1.89	7.1	496		604.8	496	16.02	15.37	1.03
135	Well 135	05-17-06	1050	Logar	1.81	6.9		570.0	570.0	467	15.45	14.81	1.05
136	Well 136	11-10-04	0000	Logar	1.77	5.5	358		436.5	358	11.67	11.56	0.23
138	Well 138	11-10-04	0000	Logar	1.83	5.6	483		588.9	483	15.03	14.72	0.52
139	Well 139	11-16-04	0000	Logar	1.87	8.9	530		646.2	530	17.15	15.69	2.23
140	Well 140	11-16-04	0000	Logar	1.85	7	458		558.4	458	15.87	14.55	2.17
140	Well 140	05-29-06	1220	Logar									
141	Well 141	11-18-04	0000	Logar	3.12	9	468		570.6	468	22.64	21.82	0.93
143	Well 143	11-16-04	0000	Logar	2.02	9.3	526		641.3	526	16.59	16.03	0.86
143	Well 143	05-29-06	1200	Logar									
147	Well 147	11-11-04	0000	Central Kabul	0.91	3.8	229		279.2	229	7.29	7.00	0.99
148	Well 148	09-26-04	0000	Central Kabul	3.81	4.8	320		390.2	320	22.48	22.12	0.41
148	Well 148	06-05-06	1015	Central Kabul									
150	Well 150	10-31-04	0000	Central Kabul	6.45	1.05	86		104.9	86	4.50	4.67	-0.91
151	Well 151	10-31-04	0000	Central Kabul	3.04	4.2	202		246.3	202	20.60	19.68	1.15
152	Well 152	11-11-04	0000	Central Kabul	1.07	3.2	211		257.3	211	7.68	7.49	0.64
152	Well 152	06-05-06	1000	Central Kabul									
153	Well 153	11-11-04	0000	Central Kabul	21.59	22.5	401		488.9	401	167.66	177.04	-1.36
153	Well 153	11-17-04	0000	Central Kabul	20.8	20.4	453		552.3	453	148.34	154.28	-0.98
153	Well 153	05-20-06	1305	Central Kabul	15.14	17.4		648.7	648.7	532	79.86	81.55	-0.53
154	Well 154	11-11-04	0000	Central Kabul	2.2	5.7	444		541.4	444	16.06	15.51	0.88
156	Well 156	11-20-04	0000	Central Kabul	2	14.9	500		609.6	500	21.94	20.40	1.82
156	Well 156	05-27-06	1000	Central Kabul									
157	Well 157	11-20-04	0000	Central Kabul	6.8	13.7	297		362.1	297	55.53	54.14	0.63
157	Well 157	05-27-06	1010	Central Kabul									
159	Well 159	11-20-04	0000	Logar	1.87	8.99	410		499.9	410	16.38	16.09	0.45
160	Well 160	11-17-04	0000	Central Kabul	1.98	7.3	489		596.2	489	16.79	16.19	0.91
162.2	Well 162.2	05-31-06	1020	Central Kabul									
163	Well 163	11-17-04	0000	Central Kabul	1.82	5.6	374		456.0	374	13.40	12.06	2.61
163	Well 163	05-31-06	1040	Central Kabul									
164	Well 164	11-21-04	0000	Central Kabul	2.61	7.6	451		549.9	451	20.45	14.81	8.00
165	Well 165	11-21-04	0000	Central Kabul	1.28	4.5	318		387.7	318	10.72	10.08	1.55
165	Well 165	05-22-06	1000	Central Kabul	1.39	4.9		374.8	374.8	307	11.81	10.60	2.71
166.2	Well 166.2	11-21-04	0000	Central Kabul	12.42	18.4	108		131.7	108	138.67	142.86	-0.74
167	Well 167	11-02-04	0000	Central Kabul	2.65	7.4	211		257.3	211	16.66	15.27	2.18
167	Well 167	06-20-06	0945	Central Kabul									
168	Well 168	11-02-04	0000	Central Kabul	2.26	15.8	277		337.7	277	15.24	12.85	4.25
168	Well 168	05-22-06	1040	Central Kabul	2.23	15		363.5	363.5	298	15.44	14.19	2.11
169.2	Well 169.2	11-04-04	0000	Central Kabul	1.37	5.5	357		435.3	357	10.50	10.07	1.05

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Cl (mg/L)	SO_4 (mg/L)	F (mg/L)	Br (mg/L)	SiO_2 (mg/L)	ROE	SOC	ROESOC	Ion Balance Charge	Ion Balance Percent	ROESC	Al (µg/L)	Sb (µg/L)	As (µg/L)	As (µg/L) (R or D)
118	11-01-04	66	42.8	0.26	0.16	25	454					0.49	1.9	0.2		0.7
119	11-03-04	53.6	70.1	0.27	0.24	26	571	540	1.06	0.9	4.53	0.6	0.9	0.1		1.5
120	11-08-04	11.8	43.2	0.27	0.11	22	386					0.59	1.7	0.1		1.8
121	11-08-04	12.2	48.6	0.29		24	465			-0.26	-1.5	0.62	0.9	0.2		0.2
124	05-27-06															
125	11-22-04	700	95.7	0.3	0.34	29	1,750	1,785	0.98	0.89	1.41	0.51	1.6	0.2		1.1
126	11-22-04	76.1	52.9	0.22	0.18	30	614	602	1.02	1.15	5.22	0.58	13.1	0.1		2.2
129	05-24-06	90.6	67.5	0.29	0.12	31.7		793		-1.95	-6.89		2	<0.1	3.2	3.2
130	11-03-04	108	58.7	0.29	0.22	29	647	655	0.99	-0.17	-0.75	0.71	1.1	0.1		1.9
131	09-23-04	55	44.7	0.2	0.14	27	513					0.61	1.6	0.1		2.4
132	11-22-04	334	113	0.15	0.36	25	1,690					0.61	1.6	0.2		0.6
133	11-22-04	120	128	0.2	0.27	38	894	907	0.99	-0.03	-0.08	0.61	1.6	0.1		2.3
133	05-27-06															
134	11-22-04	171	168	0.6	0.41	33	1,020	1,024	1	0.17	0.46	0.61	2.4	1		5.5
135	11-10-04	94.5	134	0.51	0.37	23	843	846	1	-0.14	-0.44	0.6	2.4	0.2		1.1
135	05-17-06	92	138	0.41	0.23	22.9		897		-2.35	-7.21		1	<0.1	1.6	1.6
136	11-10-04	85.9	95	0.39	0.23	24	613	623	0.98	-0.21	-0.9	0.57	0.8	0.2		2
138	11-10-04	98.4	110	0.6	0.3	28	763	787	0.97	-0.3	-1	0.58	3.2	0.1		2.4
139	11-16-04	98.6	111	0.46	0.26	28	842	845	1	1.05	3.22	0.59	2.5	0.3		1.2
140	11-16-04	89.4	138	0.49	0.42	31	843	817	1.03	0.73	2.41	0.62	2.4	0.1		1.1
140	05-29-06															
141	11-18-04	201	326	0.64	0.53	41	1,260					0.63	4	0.2		10.1
143	11-16-04	99.6	130	0.48	0.39	26	860	870	0.99	-0.15	-0.46	0.6	2.4	0.2		1.8
143	05-29-06															
147	11-11-04	22.9	85.4	0.49	0.16	14	396					0.59	1.5	0.1		0.3
148	09-26-04	327	312	0.3	0.9	24	1,370	1,304	1.05	-0.52	-1.16	0.73	2	0.1		0.6
148	06-05-06															
150	10-31-04	37.4	90.8	0.63	0.18	10.1	296					0.72	3.3	0.1		0.3
151	10-31-04	307	335	0.59	0.78	26	1,220	1,161	1.05	0.45	1.13	0.66	8.3	0.1		1.7
152	11-11-04	32.6	113	0.52	0.17	14	440					0.61	1.2	0.2		0.4
152	06-05-06															
153	11-11-04	4,190	2,440	1.21	7.71	20	10,900	10,262	1.06	-11.17	-3.26	0.71	22.4	0.7		2.8
153	11-17-04	3,590	2,110	1.32	6.14	19	9,350	8976	1.04	-7.54	-2.5	0.67	4.8	0.6		1.8
153	05-20-06	1,650	1,170	<0.05	2.43	10.8				-5.03	-3.09		3	0.4	1.8	1.8
154	11-11-04	159	103	0.23	0.33	36	840	840	1	0.03	0.1	0.59	2.4	0.2		8.5
156	11-20-04	213	211	0.28	0.32	27	1,200	1,201	1	-0.05	-0.12	0.62	4.6	0.2		9.9
156	05-27-06															
157	11-20-04	623	1,470	0.77	1.8	18	3,740	3,460	1.08	-2.01	-1.81	0.76	1.3	1.3		4.5
157	05-27-06															
159	11-20-04	132	200	0.56	0.36	18.9	857					0.6	1.1	0.2		22.7
160	11-17-04	136	124	0.23	0.23	34	881					0.6	2.4	0.1		4.7
162.2	05-31-06															
163	11-17-04	99.6	85.4	0.25	0.23	30	673	692	0.97	0.73	2.86	0.58	2.4	0.3		0.9
163	05-31-06															
164	11-21-04	127	106	0.26	0.29	34	884					0.64	3.2	0.1		1.8
165	11-21-04	91.7	54.5	0.18	0.23	24	557	582	0.96	-0.23	-1.06	0.56	3.2	0.4		1
165	05-22-06	111	63.5	0.17	0.17	23.1		667		-1.14	-4.68		1	<0.1	1.7	1.7
166.2	11-21-04	2,750	3,030	0.25	6.05	16	9,220					0.77	3.2	0.4		0.1
167	11-02-04	91.1	407	0.48	0.46	34	1,080	1,023	1.06	0.24	0.73	0.71	1.4	0.1		1.9
167	06-20-06															
168	11-02-04	122	186	0.69	0.35	23	917					0.66	2	0.1		0.7
168	05-22-06	142	203	<0.05	0.23	22.9				-2.23	-6.84		1	<0.1	1.1	1.1
169.2	11-04-04	69	47.4	0.46	0.15	22	552					0.57	1.7	0.2		0.3

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Ba (µg/L)	Be (µg/L)	B (µg/L)	Cd (µg/L)	Cr (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L)	D	Fe (µg/L)
118	Well 118	11-01-04	0000	Paghman/Upper Kabul	48	0.03	943	0.02	1	1.17	0.9	9		
119	Well 119	11-03-04	0000	Paghman/Upper Kabul	60	0.03	859	0.02	1.6	1.81	1.5	11		
120	Well 120	11-08-04	0000	Paghman/Upper Kabul	72	0.03	356	0.02	8.4	0.52	2.4	6		
121	Well 121	11-08-04	0000	Paghman/Upper Kabul	68	0.03	552	0.03	0.4	1.24	6.6	10		
124	Well 124	05-27-06	0900	Central Kabul										
125	Well 125	11-22-04	0000	Central Kabul	257	0.06	1,000	0.06	0.5	1.1	3.2	30		
126	Well 126	11-22-04	0000	Central Kabul	67	0.03	785	0.02	0.4	0.84	1	3		
129	Well 129	05-24-06	1255	Central Kabul	84		710	<0.05	1	0.38	0.9			<20
130	Well 130	11-03-04	0000	Paghman/Upper Kabul	179	0.03	828	0.02	0.7	0.79	4.9	3		
131	Well 131	09-23-04	0000	Central Kabul	59	0.03	695	0.02	0.4	0.27	1	4.8		
132	Well 132	11-22-04	0000	Central Kabul	172	0.06	799	0.04	3.2	0.85	4.8	9		
133	Well 133	11-22-04	0000	Central Kabul	73	0.03	1,110	0.02	0.4	1.96	3	3		
133	Well 133	05-27-06	0930	Central Kabul										
134	Well 134	11-22-04	0000	Logar	66	0.03	1,510	0.12	0.4	0.49	30.6	8		
135	Well 135	11-10-04	0000	Logar	62	0.03	1,410	0.02	8.1	3.17	1.4	3		
135	Well 135	05-17-06	1050	Logar	50		1,210	<0.05	7	0.19	1.8			<20
136	Well 136	11-10-04	0000	Logar	64	0.03	997	0.04	0.4	0.64	0.8	12		
138	Well 138	11-10-04	0000	Logar	100	0.03	1,510	0.02	2.7	2.05	1.2	14		
139	Well 139	11-16-04	0000	Logar	91	0.03	1,780	0.02	2.6	1.24	1.2	5		
140	Well 140	11-16-04	0000	Logar	62	0.03	1,290	0.02	6.6	1.9	1.5	8		
140	Well 140	05-29-06	1220	Logar										
141	Well 141	11-18-04	0000	Logar	71	0.03	2,240	0.03	6.7	0.73	2.3	3		
143	Well 143	11-16-04	0000	Logar	80	0.03	1,450	0.19	11	1.1	1.4	3		
143	Well 143	05-29-06	1200	Logar										
147	Well 147	11-11-04	0000	Central Kabul	40	0.03	136	0.02	1	2.3	0.9	5		
148	Well 148	09-26-04	0000	Central Kabul	65	0.03	1,460	0.07	1.7	0.36	3.4	3.2		
148	Well 148	06-05-06	1015	Central Kabul										
150	Well 150	10-31-04	0000	Central Kabul	36	0.03	142	0.02	0.4	3.96	0.8	213		
151	Well 151	10-31-04	0000	Central Kabul	24	0.03	1,060	0.04	0.4	0.26	1.4	70		
152	Well 152	11-11-04	0000	Central Kabul	48	0.03	159	0.02	1.7	2.16	1.1	19		
152	Well 152	06-05-06	1000	Central Kabul										
153	Well 153	11-11-04	0000	Central Kabul	33	0.21	7,900	0.16	3.1	4.8	12.3	30		
153	Well 153	11-17-04	0000	Central Kabul	31	0.18	7,600	0.36	5.2	3.19	8.8	30		
153	Well 153	05-20-06	1305	Central Kabul	23		6,660	0.19	1	0.65	9.6			<20
154	Well 154	11-11-04	0000	Central Kabul	71	0.03	1,490	0.02	0.4	4.01	3.9	10		
156	Well 156	11-20-04	0000	Central Kabul	195	0.03	1,190	0.02	0.4	0.98	2.2	4		
156	Well 156	05-27-06	1000	Central Kabul										
157	Well 157	11-20-04	0000	Central Kabul	15	0.06	160	0.04	28	0.55	6.1	9		
157	Well 157	05-27-06	1010	Central Kabul										
159	Well 159	11-20-04	0000	Logar	62	0.03	1,060	0.02	0.4	0.96	1.2	6		
160	Well 160	11-17-04	0000	Central Kabul	178	0.03	1,180	0.02	0.4	1.26	1.2	4		
162.2	Well 162.2	05-31-06	1020	Central Kabul										
163	Well 163	11-17-04	0000	Central Kabul	65	0.03	1,250	0.02	16	2.45	1.5	3		
163	Well 163	05-31-06	1040	Central Kabul										
164	Well 164	11-21-04	0000	Central Kabul	81	0.03	1,130	0.06	0.4	1.14	6.3	12		
165	Well 165	11-21-04	0000	Central Kabul	145	0.03	1,250	2.38	3.3	3.82	2	5		
165	Well 165	05-22-06	1000	Central Kabul	137		850	<0.05	11	0.24	0.6			<20
166.2	Well 166.2	11-21-04	0000	Central Kabul	18	0.03	1,650	0.15	0.9	1.41	9.7	207		
167	Well 167	11-02-04	0000	Central Kabul	30	0.03	521	0.29	5.2	0.48	2.1	4		
167	Well 167	06-20-06	0945	Central Kabul										
168	Well 168	11-02-04	0000	Central Kabul	36	0.03	772	0.02	9.7	0.64	1.5	7		
168	Well 168	05-22-06	1040	Central Kabul	36		820	<0.05	11	0.38	1.2			<20
169.2	Well 169.2	11-04-04	0000	Central Kabul	95	0.03	747	0.02	1.6	2.02	5.3	6		

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Pb (µg/L)	Li (µg/L)	Mn ICPMS µg/L	Mn (µg/L)	Mo (µg/L)	Ni (µg/L)	Se (µg/L)	Ag (µg/L)	Sr (µg/L)	Th (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)	Comment
118	11-01-04	0.1	119	0.6	1.5	1	10.9	0.2	0.1	278	0.02	4.27	0.49	4.3	FAFU
119	11-03-04	0.09	104	3.6	3.4	1.2	9.48	1.3	0.1	911	0.02	6.11	0.85	1.4	FAFU
120	11-08-04	0.05	44.6	1.2	1.2	1.7	0.79	1.1	0.1	536	0.02	5.11	3.46	44.1	FAFU
121	11-08-04	0.13	18	12	11.3	1.1	2.21	1.1	0.1	695	0.02	5.98	2.58	924	FAFU
124	05-27-06														
125	11-22-04	0.74	152	9	9	3.1	0.7	0.7	0.2	1,900	0.04	7.1	5.29	1,250	FAFU
126	11-22-04	0.1	90.1	1.3	1.3	1	14.5	1.2	0.1	828	0.02	6.32	1.31	26.9	FAFU
129	05-24-06	0.09	85	<1		2.1	22.7	2	<0.05	1,010		9.8	1.3	9	CFC,3H,FAFU
130	11-03-04	0.43	118	0.9	0.9	2.2	7.92	1.5	0.1	975	0.02	6.5	3.95	27.9	FAFU
131	09-23-04	0.54	109	0.3	0.4	1.2	5.55	1.2	0.1	701	0.02	4.78	1.53	139	FAFU
132	11-22-04	0.27	167	0.3	0.9	0.6	4.09	1.2	0.2	2,140	0.04	4.93	6.89	40.2	FAFU
133	11-22-04	1.73	164	35.2	35.7	3.3	19.6	3.6	0.1	818	0.02	9.14	1.31	16,50	FAFU
133	05-27-06														
134	11-22-04	7.66	263	15.6	16.2	39	3.69	6.2	0.1	1,510	0.02	9.16	6.44	780	FAFU
135	11-10-04	0.08	211	5.1	5.1	4.5	2.32	2.3	0.1	1,230	0.02	7.48	11.4	3.1	FAFU
135	05-17-06	0.61	175	<1		3.6	0.8	4	<0.05	1,470		8.9	15.3	15	CFC,3H,FAFU
136	11-10-04	0.13	151	2.2	2	3.5	2.09	1.3	0.1	1,030	0.02	6.12	2.02	2.1	FAFU
138	11-10-04	0.04	272	3.3	4.3	4.4	5.51	7.8	0.1	941	0.02	7.23	3.27	2.1	FAFU
139	11-16-04	1.28	314	105	108	2.9	5.16	1.4	0.1	1,860	0.02	16.3	4.04	5.8	FAFU
140	11-16-04	0.09	186	3.3	3.2	3.4	6.13	2.6	0.1	1,520	0.02	15.7	6.41	6.3	FAFU
140	05-29-06														
141	11-18-04	0.06	341	0.1	1	11.7	1.31	35.7	0.1	2,410	0.02	21.6	5.53	51.6	FAFU
143	11-16-04	2.35	245	4.8	4.8	3.9	2.28	3.3	0.1	1,460	0.02	10.4	4.77	2,100	FAFU
143	05-29-06														
147	11-11-04	0.08	12.5	4.2	3.5	4	2.02	1.5	0.1	994	0.02	4.7	1.71	52	FAFU
148	09-26-04	0.13	173	3.3	3.4	3.2	1.97	2.7	0.1	2,430	0.02	12.3	7.76	12.5	FAFU
148	06-05-06														
150	10-31-04	0.04	1.5	16.4	16.7	1.8	0.69	0.4	0.1	114	0.02	0.72	0.11	1.4	FAFU
151	10-31-04	0.04	78.1	3	2.7	8.2	1.34	2.9	0.1	2,080	0.02	7.99	2.81	2.5	FAFU
152	11-11-04	0.1	13.8	4.9	4.7	4.1	0.97	1.9	0.1	1,090	0.02	5.24	2.59	119	FAFU
152	06-05-06														
153	11-11-04	1.47	705	255	236	43.1	9.74	5.6	0.7	10,500	0.14	75.9	11	253	FAFU
153	11-17-04	6.63	463	211	200	42.5	14.1	12.7	0.6	8,840	0.12	60.2	7.49	256	FAFU
153	05-20-06	3.1	518	17		55.3	21.8	16	<0.05	5,610		28.4	0.7	1,010	CFC,3H,FAFU
154	11-11-04	0.14	153	34.9	35.4	2.5	11	0.5	0.1	945	0.02	7.3	1.45	11.4	FAFU
156	11-20-04	0.04	234	931	901	2.8	4.96	22.6	0.1	1,680	0.02	5.98	5.96	3.3	FAFU
156	05-27-06														
157	11-20-04	4.66	257	8.6	16.1	6.5	4.72	22.7	0.2	8	0.04	36.2	6.4	12	FAFU
157	05-27-06														
159	11-20-04	0.04	235	33.8	33	7.3	1.27	0.9	0.1	1,150	0.02	2.55	1.35	34.1	FAFU
160	11-17-04	0.04	164	20.6	21.4	1.8	6.35	0.8	0.1	1,810	0.02	11.4	2.47	4	FAFU
162.2	05-31-06														
163	11-17-04	0.53	164	1.2	5.2	1.4	3.14	0.5	0.1	267	0.02	5.83	4.83	6	FAFU
163	05-31-06														
164	11-21-04	0.12	180	4	3.8	1.9	6.37	0.6	0.1	1590	0.02	10.2	1.63	39.9	FAFU
165	11-21-04	7.88	119	7	6.8	1.1	0.6	1.8	0.1	872	0.02	6.27	4.63	2,920	FAFU
165	05-22-06	0.16	127	<1		0.8	0.6	2	<0.05	755		4.5	6.7	8	CFC,3H,FAFU
166.2	11-21-04	0.54	207	10.6	66.6	5.5	9.42	0.2	0.1	12,400	0.02	17.6	4.01	453	FAFU
167	11-02-04	0.04	23.9	8.6	8.4	5.1	1.35	10.8	0.1	2,020	0.02	12.4	12.5	18	FAFU
167	06-20-06														
168	11-02-04	0.04	72	3.7	3.5	7.8	11.8	1.6	0.1	2,010	0.02	13.5	7.09	2.4	FAFU
168	05-22-06	0.09	83	2		7	28.3	3	<0.05	2,290		14.5	6.7	13	3H,FAFU
169.2	11-04-04	0.04	61.5	2.3	4.7	2.8	2.03	0.7	0.1	845	0.02	11	8.42	153	FAFU

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Sample water level (m)	Water temperature (°C)	Spec. cond. (µS/cm)	Total dissolved solids	pH field	O_2 (mgL)	NO_2 N field (mg/L)	NO_3 N field (mg/L)	Total coli count per 100 mL
170	Well 170	11-04-04	0000	Central Kabul		16.2	1,472		6.94	6.9	0	5-10	1
170	Well 170	06-18-06	1150	Central Kabul	10.61	17.6	1,662	0.76	7.44		0	2-5	9.8
171	Well 171	11-22-04	0000	Central Kabul		15.3	1,368		7.39		0	2-5	32
172	Well 172	11-20-04	0000	Central Kabul	11.14	15.2	1,522		7.25	2.4	0	10-20	1
172	Well 172	05-22-06	1145	Central Kabul	10.32	22.5	1,627	0.76	7.35		0	2-5	1
173	Well 173	11-20-04	0000	Central Kabul	7.34	14.9	903		7.71	2.1	0	2-5	19
173	Well 173	06-18-06	1050	Central Kabul	7.61	16.1	950	0.44	7.84		0	1-2	>2,420
174	Well 174	11-20-04	0000	Central Kabul	16.98	15.5	840		7.49	8.2	0	5-10	82
175	Well 175	11-18-04	0000	Central Kabul	21.82	18.3	694		7.92	8.1	0	2-5	22
176	Well 176	11-18-04	0000	Central Kabul	6.5	15.4	2,375		7.79	6.1	0	1-2	613
177	Well 177	11-21-04	0000	Central Kabul	6.9	10.9	6,390		8.08	8.7	1.5-3.0	20-50	>2,420
178	Well 178	11-17-04	0000	Central Kabul	11.83	14.9	1,080		7.4	2.8	0	2-5	10
180	Spring 180	05-17-06	0945	Central Kabul		18.6	410	0.19	7.67		0	1-2	>2,420
181	Chari Sib Spring	05-17-06	1135	Logar		14.8	833	0.38	7.45		0	1-2	980
182	Well 182	06-02-07	1155	Paghman/Upper Kabul	8.08	16	755	0.3	7.88		0	2-5	
183	Hootkhel-Nowbahar Pump Station	06-04-07	0905	Central Kabul	4.84	18.1	1,196	0.55	8.15		0	0-1	
184	Well 184	06-06-07	0920	Paghman/Upper Kabul	3.17	15.6	1,319	0.45	7.74		0	2-5	
185	Well 185	06-16-07	1050	Central Kabul	13.76	20.3	5,060	2.15	8.29		0	5-10	
186	Well 186	06-18-07	0940	Central Kabul	25.05	18.5	706	0.32	8.28		0	2-5	
187	Hotuk Pump Station	06-20-07	1030	Logar	7.97	15.4	1,155	0.51	7.82		0	1-2	
201	Well 201	06-13-06	1045	Logar	4.32	14.6	1,106	0.52	7.99		0	1-2	6.3
202	Well 202	08-01-04	0000	Logar	6.07	15.4	1,045			3.9	0	1-2	1
202	Well 202	11-16-04	0000	Logar	11	14	932		7.76	10.5	0	1-2	1
202	Well 202	06-13-06	1000	Logar	6.78	15.1	693	0.52	7.81		0	1-2	3.1
203	Well 203	05-20-06	1110	Logar		16.2	940	0.44	7.98		0	0-1	1
204	Well 204	06-13-06	1020	Logar	7.9	14.4	1,225	0.58	8.02		0	1-2	1
205	Well 205	08-01-04	0000	Logar	11	16	1,512			1.1	0	2-5	13
205	Well 205	11-18-04	0000	Logar		16.3	1,527		7.41	4.6	0	2	4
206	Well 206	08-01-04	0000	Logar	12	15.6	1,280			3	0	1-2	4
208	Well 208	09-20-04	0000	Central Kabul	17.96	15.5	1,079		7.36	9	0	5-10	1
208	Well 208	05-20-06	0930	Central Kabul	15.02	18.3	1,127	0.55	7.71		0	1-2	1
210	Well 210	05-31-06	0940	Central Kabul	8.38	16.7	1,112	0.56	7.74		0	1-2	1
211	Well 211	07-31-04	0000	Paghman/Upper Kabul	5.59	15.4	801			5.4	0	5	
211	Well 211	06-08-06	0915	Paghman/Upper Kabul	4.27	16.1	916	0.45	7.7		0	1-2	161
212	Well 212	06-08-06	0950	Paghman/Upper Kabul	4.68	15	948	0.49	7.66		0	1-2	7.5
213	Well 213	05-15-06	1305	Paghman/Upper Kabul	4.42	15.1	799	0.43	7.55		0	2-5	1
214	Well 214	06-11-06	1245	Paghman/Upper Kabul	8.78	16.3	688	0.3	7.65		0	1-2	177
216	Well 216	07-31-04	0000	Paghman/Upper Kabul	26.14	15.1	450			11.7	0	1-2	
216	Well 216	11-07-04	0000	Paghman/Upper Kabul	20.64	14.5	515		7.68	13.5	0	2-5	1
216	Well 216	06-11-06	1125	Paghman/Upper Kabul	25.71	15.4	418	0.17	7.9		0	1-2	4.1
217	Well 217	11-07-04	0000	Paghman/Upper Kabul	26.32	15.5	497		7.69	14.9	0	1-2	1

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month-day-year)	*E. coli* count per 100 mL	pH lab	Spec. cond. Lab (µS/cm)	NO_4 N (mg/L)	NO_2 N mg/L)	NO_2-NO_3N (mg/L)	NO_3 N (mg/L)	NO_3 NO_3 (mg/L)	Total N (mg/L)	PO_4 P (mg/L)	Ca (mg/L)	Mg (mg/L)	Hardness (mg/L)	Na (mg/L)
170	11-04-04	1				0.004	9.97					72	94.4	568.6	99.7
170	06-18-06	1													
171	11-22-04	1				0.004	6.01	6	26.6			95	61.8	491.7	96.1
172	11-20-04	1				0.004	18.3					91	89.1	594.2	90.6
172	05-22-06	1						23.49	104			101.6	98.1	658.7	101
173	11-20-04	1				0.004	4.04	4	17.7			35	55.2	314.7	72.1
173	06-18-06	6.3													
174	11-20-04	1				0.02	10.1	10.1	44.7			96	28.7	357.9	41.3
175	11-18-04	1				0.004	3.91					40	22.6	193	68.4
176	11-18-04	1				0.007	1.79	1.8	8			83	175	928	157
177	11-21-04	11				1.4	42.5	41.1	181.9			144	506	2443.5	608
178	11-17-04	1				0.004	8.51					64	68.4	441.5	58.7
180	05-17-06	5.2						3.30	14.6			50.6	10.6	170	14.6
181	05-17-06	1						1.37	6.08			68.9	30.4	297.2	61.3
182	06-02-07			755				8.99	39.8			103.3	23		22
183	06-04-07			1196				0.61	2.71			35.6	88.3		85.8
184	06-06-07			1319				13.15	58.2			83	74.7		87.9
185	06-16-07			5060				17.78	78.7			221.4	266.2		524.7
186	06-18-07			706				6.73	29.8			42.6	29.2		38.8
187	06-20-07			1155				1.56	6.89			56.2	79.4		70.4
201	06-13-06	1													
202	08-01-04	1	7.9	828	0.02	0.004	1.96			2.02	0.003	40	63.7	362.2	64.9
202	11-16-04	1				0.004	2.05					39	64	361	63.4
202	06-13-06	1													
203	05-20-06	1						1.97	8.7			39.1	61.8	352.2	70.4
204	06-13-06	1													
205	08-01-04	1	7.6	1460	0.02	0.004	3.84			3.67	0.062	54	91.4	511.3	159
205	11-18-04	1				0.004	3.61					50	89	491.4	161
206	08-01-04	1	7.8	1280	0.02	0.004	3.75			3.81	0.009	38	102	515	133
208	09-20-04	1	7.6	1010		0.004	9.43					72	53.5	400.1	68.4
208	05-20-06	1						9.62	42.6			75.3	57.6	425.3	72.6
210	05-31-06	1													
211	07-31-04		7.6	801	0.02	0.004	6.06			5.86	0.003	75	50.9	396.9	56.6
211	06-08-06	1													
212	06-08-06	1													
213	05-15-06	1						2.04	9.05			73.2	50	388.7	47.8
214	06-11-06	1													
216	07-31-04		7.8	407	0.02	0.004	2.22			2.14	0.014	63	13.4	212.5	12.4
216	11-07-04	1				0.004	2.79					71	16.6	245.7	14.8
216	06-11-06	1													
217	11-07-04	1				0.004	3.09					67	15.3	230.3	14.9

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	SAR	K (mg/L)	Alk mg/L as $CaCO_3$ (D)	Alk mg/L as HCO_3 (R)	Alk mg/L as HCO_3 (R&D)	Alk mg/L as $CaCO_3$ R&D	sum meq cations	sum meq anions	Percent charge imbalance
170	Well 170	11-04-04	0000	Central Kabul	1.82	6.1	410		499.9	410	16.19	14.70	2.41
170	Well 170	06-18-06	1150	Central Kabul									
171	Well 171	11-22-04	0000	Central Kabul	1.89	16.5	369		449.9	369	14.65	13.27	2.47
172	Well 172	11-20-04	0000	Central Kabul	1.62	14.1	495		603.5	495	16.49	15.06	2.27
172	Well 172	05-22-06	1145	Central Kabul	1.71	14.5		630.0	630.0	517	18.25	16.36	2.74
173	Well 173	11-20-04	0000	Central Kabul	1.77	5.5	318		387.7	318	9.76	9.52	0.62
173	Well 173	06-18-06	1050	Central Kabul									
174	Well 174	11-20-04	0000	Central Kabul	0.95	8.3	263		320.7	263	9.26	7.18	6.35
175	Well 175	11-18-04	0000	Central Kabul	2.14	2.4	168		204.8	168	6.97	6.77	0.74
176	Well 176	11-18-04	0000	Central Kabul	2.24	5.5	312		380.4	312	26.13	26.04	0.08
177	Well 177	11-21-04	0000	Central Kabul	5.35	31.6	384		468.2	384	77.86	73.50	1.44
178	Well 178	11-17-04	0000	Central Kabul	1.22	5.1	362		441.4	362	11.75	11.14	1.33
180	Spring 180	05-17-06	0945	Central Kabul	0.49	8.5		202.4	202.4	166	4.29	4.05	1.41
181	Chari Sib Spring	05-17-06	1135	Logar	1.55	4.5		390.0	390.0	320	8.83	8.89	-0.18
182	Well 182	06-02-07	1155	Paghman/Upper Kabul		3.7		301.4	301.4	247	8.18	7.71	1.50
183	Hootkhel-Nowbahar Pump Station	06-04-07	0905	Central Kabul		4.8		551.0	551.0	452	13.21	13.51	-0.56
184	Well 184	06-06-07	0920	Paghman/Upper Kabul		6.6		471.9	471.9	387	14.54	13.18	2.46
185	Well 185	06-16-07	1050	Central Kabul		12.9		254.6	254.6	209	57.05	56.76	0.13
186	Well 186	06-18-07	0940	Central Kabul		6.1		205.6	205.6	169	6.48	6.22	0.99
187	Hotuk Pump Station	06-20-07	1030	Logar		5.1		511.2	511.2	419	12.81	12.94	-0.25
201	Well 201	06-13-06	1045	Logar									
202	Well 202	08-01-04	0000	Logar	1.48	4.4	327		398.7	327	10.40	9.93	1.14
202	Well 202	11-16-04	0000	Logar	1.45	4.6	329		401.1	329	10.31	10.08	0.58
202	Well 202	06-13-06	1000	Logar									
203	Well 203	05-20-06	1110	Logar	1.63	4.7		415.0	415.0	340	10.44	10.26	0.44
204	Well 204	06-13-06	1020	Logar									
205	Well 205	08-01-04	0000	Logar	3.06	6.6	534		651.1	534	17.62	16.96	0.96
205	Well 205	11-18-04	0000	Logar	3.16	6.5	527		642.6	527	17.30	16.88	0.61
206	Well 206	08-01-04	0000	Logar	2.55	6.3	501		610.9	501	16.60	16.09	0.78
208	Well 208	09-20-04	0000	Central Kabul	1.49	14.2	280		341.4	280	11.52	10.08	3.34
208	Well 208	05-20-06	0930	Central Kabul	1.53	15.3		410.0	410.0	336	12.25	11.51	1.55
210	Well 210	05-31-06	0940	Central Kabul									
211	Well 211	07-31-04	0000	Paghman/Upper Kabul	1.24	4.5	339		413.3	339	10.69	9.49	2.96
211	Well 211	06-08-06	0915	Paghman/Upper Kabul									
212	Well 212	06-08-06	0950	Paghman/Upper Kabul									
213	Well 213	05-15-06	1305	Paghman/Upper Kabul	1.05	6.7		375.8	375.8	308	10.19	10.00	0.49
214	Well 214	06-11-06	1245	Paghman/Upper Kabul									
216	Well 216	07-31-04	0000	Paghman/Upper Kabul	0.37	2.4	195		237.8	195	4.89	4.49	2.17
216	Well 216	11-07-04	0000	Paghman/Upper Kabul	0.41	2.9	235		286.5	235	5.69	5.42	1.18
216	Well 216	06-11-06	1125	Paghman/Upper Kabul									
217	Well 217	11-07-04	0000	Paghman/Upper Kabul	0.43	2.7	191		232.9	191	5.37	4.40	4.96

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Cl (mg/L)	SO_4 (mg/L)	F (mg/L)	Br (mg/L)	SiO_2 (mg/L)	ROE	SOC	ROESOC	Ion Balance Charge	Ion Balance Percent	ROESC	Al (µg/L)	Sb (µg/L)	As (µg/L)	As (µg/L) (R or D)
170	11-04-04	161	94.1	0.41	0.24	34	863					0.59	3.1	0.2		1.8
170	06-18-06															
171	11-22-04	161	64.7	0.24	0.16	29	782	772	1.01	0.74	2.62	0.57	1.6	0.2		0.8
172	11-20-04	126	77.2	0.35	0.41	32	886					0.58	1.6	0.2		1.3
172	05-22-06	147	90.3	0.2	0.2	32.5		1,068		-2.37	-6.19		<1	<0.1	1.6	1.6
173	11-20-04	63.5	65.9	0.29	0.19	19	523	525	1	-0.24	-1.22	0.58	2.4	0.2		1.5
173	06-18-06															
174	11-20-04	39.2	39	0.33	0.09	25	508	480	1.06	1.27	7.43	0.6	0.8	0.1		0.7
175	11-18-04	52.2	93.1	0.73	0.25	24	418					0.6	1.8	0.1		1.4
176	11-18-04	386	428	0.2	1.03	28	1,530	1,459	1.05	-0.65	-1.25	0.64	1.2	0.1		0.5
177	11-21-04	1,270	1,440	0.37	2.93	32	4,710	4,447	1.06	-0.33	-0.21	0.74	2.2	0.6		8.8
178	11-17-04	87.2	69.3	0.17	0.29	26	615					0.57	1.6	0.1		1.2
180	05-17-06	7.38	25.2	0.47	<0.05	20.6				-0.76	-8.16		3	<0.1	0.3	0.3
181	05-17-06	58.6	40.6	0.27	0.08	19.0		524		-1.67	-8.73		<1	<0.1	1.1	1.1
182	06-02-07	23.4	101	0.22	0.06	19.8							6	<0.1	1.1	1.1
183	06-04-07	98.7	81.1	0.19	0.18	24.2							4	0.1	8.9	8.9
184	06-06-07	103	122	0.2	0.19	31.2							11	<0.1	1.4	1.4
185	06-16-07	887	1,323	0.46	2.36	21.4							11	<0.1	4.8	4.8
186	06-18-07	28.4	98.5	0.47	0.16	30.9							9	<0.1	2.5	2.5
187	06-20-07	83.4	106	0.25	0.16	22.7							12	<0.1	1.9	1.9
201	06-13-06															
202	08-01-04	66	73.7	0.34	0.2	26	539					0.52	0.9	0.1		0.9
202	11-16-04	68.2	75.7	0.28	0.25	28	536					0.58	0.9	0.2		0.8
202	06-13-06															
203	05-20-06	63.2	80.2	0.49	0.13	26.3		604		-1.67	-7.54		1	0.1	1.1	1.1
204	06-13-06															
205	08-01-04	112	150	0.78	0.38	22	907					0.6	3.7	0.1		2.3
205	11-18-04	115	149	0.76	0.41	23	880					0.58	1	0.1		2.3
206	08-01-04	111.5	140.5	0.41	0.35	34	865					0.68	0.8	0.1		1.6
208	09-20-04	98.4	82	0.18	0.18	29	606					0.56	1.3	0.1		1
208	05-20-06	109	82.4	0.21	0.13	30.6		732		-1.62	-6.31		<1	0.1	1.3	1.3
210	05-31-06															
211	07-31-04	48.7	64.5	0.28		28	554					0.69	1.1	0.1		0.9
211	06-08-06															
212	06-08-06															
213	05-15-06	71.4	87.4	0.26	0.1	28.5		600		-1.47	-6.86		<1	0.1	2.6	2.6
214	06-11-06															
216	07-31-04	8.3	17.1	0.17	0.06	15	244					0.54	1.4	0.1		3.1
216	11-07-04	9.2	22.4	0.16	0.06	16	304					0.59	1.5	0.1		3.4
216	06-11-06															
217	11-07-04	8.9	16.1	0.13	0.06	19	283					0.57	0.8	0.1		0.8

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Ba (µg/L)	Be (µg/L)	B (µg/L)	Cd (µg/L)	Cr (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L)	D	Fe (µg/L)
170	Well 170	11-04-04	0000	Central Kabul	83	0.03	1,380	0.02	5.7	2.41	2.1	3		
170	Well 170	06-18-06	1150	Central Kabul										
171	Well 171	11-22-04	0000	Central Kabul	95	0.03	679	0.02	0.4	0.98	1	3		
172	Well 172	11-20-04	0000	Central Kabul	198	0.03	1,200	0.02	4	4.76	3.5	4		
172	Well 172	05-22-06	1145	Central Kabul	223		1,040	<0.05	1	2.33	1.4			<20
173	Well 173	11-20-04	0000	Central Kabul	57	0.03	1,250	0.02	49	2.54	0.7	4		
173	Well 173	06-18-06	1050	Central Kabul										
174	Well 174	11-20-04	0000	Central Kabul	154	0.03	249	0.02	0.6	0.84	1.6	3		
175	Well 175	11-18-04	0000	Central Kabul	83	0.03	233	0.02	6.1	1.43	0.8	3		
176	Well 176	11-18-04	0000	Central Kabul	97	0.03	1,180	0.08	0.4	0.94	1.9	9		
177	Well 177	11-21-04	0000	Central Kabul	40	0.09	3,070	0.06	19	3.41	8.5	15		
178	Well 178	11-17-04	0000	Central Kabul	140	0.03	1,020	0.02	5	0.62	1.2	3		
180	Spring 180	05-17-06	0945	Central Kabul	52		90	<0.05	<1	0.21	0.8			<20
181	Chari Sib Spring	05-17-06	1135	Logar	104		980	<0.05	<1	0.3	0.7			<20
182	Well 182	06-02-07	1155	Paghman/Upper Kabul	56		100	<0.05	4	0.19	5.7			<20
183	Hootkhel-Nowbahar Pump Station	06-04-07	0905	Central Kabul	66		1,290	<0.05	3	0.17	1.3			<20
184	Well 184	06-06-07	0920	Paghman/Upper Kabul	103		830	<0.05	2	0.14	1.9			<20
185	Well 185	06-16-07	1050	Central Kabul	34		1,910	<0.05	24	0.41	8.3			90
186	Well 186	06-18-07	0940	Central Kabul	40		150	<0.05	5	0.1	1.6			<20
187	Hotuk Pump Station	06-20-07	1030	Logar	88		1,090	<0.05	4	0.12	1.7			<20
201	Well 201	06-13-06	1045	Logar										
202	Well 202	08-01-04	0000	Logar	67	0.03	874	0.06	3.9	0.45	1.9	3.2		
202	Well 202	11-16-04	0000	Logar	68	0.03	935	0.02	0.5	2.48	2.1	3		
202	Well 202	06-13-06	1000	Logar										
203	Well 203	05-20-06	1110	Logar	67		910	<0.05	<1	0.29	1.3			<20
204	Well 204	06-13-06	1020	Logar										
205	Well 205	08-01-04	0000	Logar	41	0.03	2,640	0.02	20	0.25	1.7	16		
205	Well 205	11-18-04	0000	Logar	38	0.03	2,440	0.1	23	0.53	1.8	3		
206	Well 206	08-01-04	0000	Logar	55	0.03	1,850	0.02	1.1	0.16	1.5	37		
208	Well 208	09-20-04	0000	Central Kabul	82	0.03	636	0.02	0.4	0.8	1.2	3.2		
208	Well 208	05-20-06	0930	Central Kabul	89		760	<0.05	<1	0.27	0.8			<20
210	Well 210	05-31-06	0940	Central Kabul										
211	Well 211	07-31-04	0000	Paghman/Upper Kabul	75	0.03	781	0.02	2.2	0.26	1.5	3.5		
211	Well 211	06-08-06	0915	Paghman/Upper Kabul										
212	Well 212	06-08-06	0950	Paghman/Upper Kabul										
213	Well 213	05-15-06	1305	Paghman/Upper Kabul	49		880	<0.05	<1	0.23	2.2			<20
214	Well 214	06-11-06	1245	Paghman/Upper Kabul										
216	Well 216	07-31-04	0000	Paghman/Upper Kabul	21	0.03	59	0.05	2.2	0.33	4.5	14		
216	Well 216	11-07-04	0000	Paghman/Upper Kabul	22	0.03	77	0.02	2.9	0.75	2	8		
216	Well 216	06-11-06	1125	Paghman/Upper Kabul										
217	Well 217	11-07-04	0000	Paghman/Upper Kabul	16	0.03	67	0.02	1.9	0.55	0.7	3		

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Pb (µg/L)	Li (µg/L)	Mn ICPMS µg/L	Mn (µg/L)	Mo (µg/L)	Ni (µg/L)	Se (µg/L)	Ag (µg/L)	Sr (µg/L)	Th (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)	Comment
170	11-04-04	0.07	186	3.5	3.5	2.2	2.56	0.5	0.1	1,920	0.02	12	8.18	9.9	FAFU
170	06-18-06														
171	11-22-04	0.06	122	0.6	1.2	1.5	16.7	0.2	0.1	475	0.02	6.73	1.42	2.4	FAFU
172	11-20-04	0.11	194	1.4	1.2	1.7	88.7	0.3	0.1	1,430	0.02	9.17	4.7	12.6	FAFU
172	05-22-06	0.4	179	1		1.6	33.1	2	<0.05	1,580		10.3	3.9	69	CFC,3H,FAFU
173	11-20-04	0.14	86.9	5.2	5.1	2.6	0.36	1.4	0.1	1,200	0.02	14.8	8.95	87	FAFU
173	06-18-06														
174	11-20-04	0.04	21.6	3.9	3.8	1.6	1.16	0.5	0.1	1,340	0.02	11.8	22.4	14.4	FAFU
175	11-18-04	0.04	10.6	4.6	2.7	7	0.4	3.8	0.1	1,080	0.02	7.44	9.8	3.4	FAFU
176	11-18-04	0.04	130	34.4	33.2	2.2	2.31	2.4	0.1	2,070	0.02	10.6	4.79	15	FAFU
177	11-21-04	0.12	514	12.4	13.2	8.7	4.4	24.3	0.3	4,350	0.06	31.5	9.88	7.1	FAFU
178	11-17-04	0.17	128	0.2	0.6	0.8	2.89	1.2	0.1	350	0.02	6.72	6.06	43.1	FAFU
180	05-17-06	0.41	4	2		6.5	0.3	<1	<0.05	516		3.5	14.2	39	CFC,3H,FAFU
181	05-17-06	1.5	129	1		1.7	0.3	1	<0.05	865		6	3.4	5	CFC,3H,FAFU
182	06-02-07	0.1	20	1		1.4	1.3	1	<0.05	617		10.3	3.1	9	CFC,3H,FAFU,DG, NFA
183	06-04-07	0.1	164	108		4.6	4.5	1	<0.05	1,140		4.43	6.9	39	CFC,3H,FAFU,DG, NFA
184	06-06-07	0.2	157	<1		2	13.1	3	<0.05	1,120		14.9	2.7	14	CFC,3H,FAFU,DG, NFA
185	06-16-07	0.45	243	1		4.3	14.5	38	<0.05	12,530		31.8	12.2	159	CFC,3H,FAFU,DG, NFA
186	06-18-07	0.47	21	4		5.8	0.6	3	<0.05	988		5.67	21.9	2030	CFC,3H,FAFU,DG, NFA
187	06-20-07	0.16	287	2		1.9	2.7	4	<0.05	1,080		5.07	3.5	130	CFC,3H,FAFU,DG, NFA
201	06-13-06														
202	08-01-04	0.18	163	0.5	0.9	2	5.33	1.2	0.1	885	0.02	3.83	1.25	15.9	FAFU
202	11-16-04	0.09	164	3.5	3.6	2.1	5.93	1.3	0.1	897	0.02	4.6	1.16	10.4	FAFU
202	06-13-06														
203	05-20-06	1.4	154	<1		2.2	5.3	2	<0.05	866		5.2	1.1	5	CFC,3H,FAFU
204	06-13-06														
205	08-01-04	0.15	266	2.7	3.5	5.6	1.68	3	0.1	2,260	0.02	12.7	3.29	2.5	FAFU
205	11-18-04	0.13	238	1.8	1.4	5.6	0.47	3.7	0.1	2,160	0.02	14.6	3.62	33.8	FAFU
206	08-01-04	0.11	196	0.5	1	2.1	5.18	2.6	0.1	1,500	0.02	16.5	2	2.3	FAFU
208	09-20-04	0.04	126	1.1	0.9	1.1	14.2	1.2	0.1	844	0.02	7.21	1.17	1.9	FAFU
208	05-20-06	0.07	104	<1		3.5	14.4	2	<0.05	873		8.5	0.8	4	CFC,3H,FAFU
210	05-31-06														
211	07-31-04	0.14	95.8	0.2	0.5	1.3	12.4	1.5	0.1	866	0.02	6.65	1.56	37.7	FAFU
211	06-08-06														
212	06-08-06														
213	05-15-06	1.3	101	3		2.8	10.9	2	<0.05	719		5.4	0.5	10	CFC,3H,FAFU
214	06-11-06														
216	07-31-04	1.45	6.1	0.4	0.7	1.3	1.32	0.4	0.1	341	0.02	3.8	2.57	273	FAFU
216	11-07-04	0.47	7.9	0.9	0.9	1.2	0.59	0.7	0.1	410	0.02	6.78	2.39	82.1	FAFU
216	06-11-06														
217	11-07-04	0.04	6.1	0.6	0.7	0.8	0.67	0.5	0.1	351	0.02	3.8	1.94	3.1	FAFU

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Sample water level (m)	Water temperature (°C)	Spec. cond. (µS/cm)	Total dissolved solids	pH field	O_2 (mgL)	NO_2 N field (mg/L)	NO_3 N field (mg/L)	Total coli count per 100 mL
217	Well 217	06-11-06	1100	Paghman/Upper Kabul	36.13	17.1	505	0.22	7.93		0	1-2	2
218	Well 218	06-20-06	1030	Central Kabul	21.72	20.1	668	0.28	8.06		0	2-5	1
219	Well 219	08-02-04	0000	Central Kabul	39.66	18.5				8	0	2-5	
219	Well 219	11-21-04	0000	Central Kabul	40.06	18.3	796		7.84	9	0	2-5	1
219	Well 219	06-20-06	1000	Central Kabul	35.93	19.1	708	0.32	8.08			2-5	7.5
220	Well 220	08-02-04	0000	Central Kabul	24.79	20.6				6.4	0	5-10	
220	Well 220	11-21-04	0000	Central Kabul	34.3	19.7	1,198		7.82	7.6	0	2-5	1
220	Well 220	06-20-06	1100	Central Kabul	23.83	20.8	1,180	0.56	7.93		0	1-2	1
221	Well 221	12-05-06	1120	Logar	5.11	13	1,145	0.45	8.21		0	1.5	
221	Well 221	02-19-07	1120	Logar	5.25	13.8	1,003	0.45	8.14		0	1-2	13.5
222	Afshar 6B	12-10-06	1220	Paghman/Upper Kabul	13.98	12.7	638	0.27	8.15		0	1-2	
223	US Embassy CAFE well	02-22-07	1400	Central Kabul		16.3	857		5.88				1
301	Istalef River at Istalef	12-04-06	1310	Shomali		5.3	196	0.08	8.45		0	0-1	
301	Istalef River at Istalef	12-18-06	0945	Shomali		4.4	175	0.06	8.56		0	0-1	
301	Istalef River at Istalef	01-02-07	1220	Shomali		4.6	156	0.04	8.43		0	0-1	
301	Istalef River at Istalef	01-16-07	1050	Shomali		4.2	136	0.04	8.51		0	0-1	
301	Istalef River at Istalef	01-30-07	1040	Shomali		7.5	190	0.07	8.48		0	0-1	
301	Istalef River at Istalef	02-13-07	1145	Shomali		7.6	158	0.05	8.49		0	0-1	
301	Istalef River at Istalef	02-27-07	1100	Shomali		6.9	146	0.05	8.59		0	0-1	
301	Istalef River at Istalef	03-13-07	1045	Shomali		6	139	0.05	8.68		0	0-1	
301	Istalef River at Istalef	03-27-07	1000	Shomali		11	105.7	0.04	8.44		0	1-2	
301	Istalef River at Istalef	04-10-07	0845	Shomali		9.4	92	0.03	8.52		0	0-1	
301	Istalef River at Istalef	04-24-07	1055	Shomali		12.5	77.8	0.02	8.57		0	0-1	
301	Istalef River at Istalef	06-14-07	0920	Shomali		14.7	103		8.75				
301	Istalef River at Istalef	07-15-07	1105	Shomali		17.8	140	0.05	8.48				
302	Panjshir River at Sayad	12-09-06	1155	Shomali		9.5	401	0.19	8.5		0	0-1	649
302	Panjshir River at Sayad	12-26-06	1210	Shomali		11.4	427	0.2	8.44		0	0-1	
302	Panjshir River at Sayad	01-09-07	1115	Shomali		9.1	424	0.2	8.4		0	0-1	
302	Panjshir River at Sayad	01-23-07	1125	Shomali		9.4	442	0.2	8.52		0	0-1	
302	Panjshir River at Sayad	02-06-07	1130	Shomali		12.5	448	0.19	8.44		0	0-1	
302	Panjshir River at Sayad	02-20-07	1140	Shomali		10.5	343	0.2	8.37		0	0-1	435
302	Panjshir River at Sayad	03-06-07	1100	Shomali		12.7	474	0.2	8.37		0	0-1	
302	Panjshir River at Sayad	03-20-07	0945	Shomali		8.9	262	0.09	8.51		0	0-1	
302	Panjshir River at Sayad	04-03-07	1210	Shomali		11.2	232.4	0.09	8.17		0	0-1	
302	Panjshir River at Sayad	04-17-07	0855	Shomali		12.3	275	0.11	8.65		0	0-1	
302	Panjshir River at Sayad	06-19-07	1030	Shomali		14.8	261		8.52				
303	Barik Ab River	12-26-06	1030	Shomali		2.3	541	0.31	8.56		0	0-1	
303	Barik Ab River	01-09-07	1015	Shomali		0.6	393	0.31	8.5		0	0-1	
303	Barik Ab River	01-23-07	1240	Shomali		0.7	508	0.36	8.48		0	0-1	
303	Barik Ab River	02-20-07	1020	Shomali		11.1	1497	0.73	8.19		0	0-1	>2,420
303	Barik Ab River	03-06-07	1000	Shomali		7.5	795	0.36	8.52		0	0-1	

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month-day-year)	*E. coli* count per 100 mL	pH lab	Spec. cond. Lab (µS/cm)	NO_4 N (mg/L)	NO_2 N mg/L)	NO_2-NO_3N (mg/L)	NO_3 N (mg/L)	NO_3 NO_3 (mg/L)	Total N (mg/L)	PO_4 P (mg/L)	Ca (mg/L)	Mg (mg/L)	Hardness (mg/L)	Na (mg/L)
217	06-11-06	1													
218	06-20-06	1													
219	08-02-04		7.6	740	0.02	0.004	6.98			6.99	0.003	55	32.5	271.2	61.3
219	11-21-04	1				0.02	7.04	7	31			56	50.2	346.6	79.1
219	06-20-06	1						5.56	24.6			47.5	25	221.6	47.6
220	08-02-04		7.8	1140	0.02	0.004	10.3			9.75	0.003	81	61.4	455.1	81.4
220	11-21-04	1				0.004	9.89					74	56.4	417.1	76
220	06-20-06														
221	12-05-06		8.1	1110										397.6	
221	02-19-07	1													
222	12-10-06		7.8	624										287.2	
223	02-22-07	1						5.42	24			54.7	52.6		48.4
301	12-04-06	>2,420													
301	12-18-06														
301	01-02-07														
301	01-16-07														
301	01-30-07														
301	02-13-07							1.27	5.6			21.3	2.83		4.19
301	02-27-07							1.26	5.59			20.5	2.63		3.95
301	03-13-07							1.68	7.42			20	2.57		3.89
301	03-27-07							1.87	8.26			16.9	2.26		3.45
301	04-10-07							1.36	6			12.4	1.6		2.31
301	04-24-07							1.24	5.5			10.6	1.44		2.02
301	06-14-07							0.49	2.16			15.1	2.04		2.96
301	07-15-07														
302	12-09-06	70													
302	12-26-06														
302	01-09-07														
302	01-23-07														
302	02-06-07							1.04	4.59			50.6	12.5		20
302	02-20-07	98.5						1.10	4.89			53.2	13.8		22.8
302	03-06-07							1.03	4.55			51.9	14.1		22.3
302	03-20-07							1.35	5.99			33	6.82		8.94
302	04-03-07							1.34	5.95			29.5	5.45		6.64
302	04-17-07							1.20	5.32			32	8.09		9.14
302	06-19-07							0.71	3.14			29.3	7.37		10.4
303	12-26-06														
303	01-09-07														
303	01-23-07	>2,420						5.87	26			88.6	70.8		
303	02-20-07							1.70	7.51			58.3	31.9		132
303	03-06-07														62.5

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	SAR	K (mg/L)	Alk mg/L as $CaCO_3$ (D)	Alk mg/L as HCO_3 (R)	Alk mg/L as HCO_3 (R&D)	Alk mg/L as $CaCO_3$ R&D	sum meq cations	sum meq anions	Percent charge imbalance
217	Well 217	06-11-06	1100	Paghman/Upper Kabul									
218	Well 218	06-20-06	1030	Central Kabul									
219	Well 219	08-02-04	0000	Central Kabul	1.62	2.9	150		182.9	150	8.27	7.58	2.18
219	Well 219	11-21-04	0000	Central Kabul	1.85	4	151		184.1	151	10.65	7.55	8.51
219	Well 219	06-20-06	1000	Central Kabul	1.39	2.8		184.7	184.7	151	6.66	6.11	2.14
220	Well 220	08-02-04	0000	Central Kabul	1.66	5.2	133		162.2	133	12.98	12.06	1.84
220	Well 220	11-21-04	0000	Central Kabul	1.62	5.2	133		162.2	133	11.97	11.40	1.22
220	Well 220	06-20-06	1100	Central Kabul									
221	Well 221	12-05-06	1120	Logar	1.73		385		469.4	385			
221	Well 221	02-19-07	1120	Logar									
222	Afshar 6B	12-10-06	1220	Paghman/Upper Kabul	0.51		259		315.8	259			
223	US Embassy CAFE well	02-22-07	1400	Central Kabul		6		382.1	382.1	313	9.50	9.21	0.77
301	Istalef River at Istalef	12-04-06	1310	Shomali									
301	Istalef River at Istalef	12-18-06	0945	Shomali									
301	Istalef River at Istalef	01-02-07	1220	Shomali									
301	Istalef River at Istalef	01-16-07	1050	Shomali									
301	Istalef River at Istalef	01-30-07	1040	Shomali									
301	Istalef River at Istalef	02-13-07	1145	Shomali		2.3		79.9	79.9	66	1.55	1.47	1.25
301	Istalef River at Istalef	02-27-07	1100	Shomali		2.2		76.5	76.5	63	1.48	1.41	1.19
301	Istalef River at Istalef	03-13-07	1045	Shomali		2.1		73.1	73.1	60	1.44	1.36	1.52
301	Istalef River at Istalef	03-27-07	1000	Shomali		2		60.6	60.6	50	1.24	1.14	1.97
301	Istalef River at Istalef	04-10-07	0845	Shomali		1.6		45.9	45.9	38	0.90	0.85	1.28
301	Istalef River at Istalef	04-24-07	1055	Shomali		1.6		39.5	39.5	32	0.78	0.73	1.67
301	Istalef River at Istalef	06-14-07	0920	Shomali		2.2		60.5	60.5	50	1.11	1.08	0.81
301	Istalef River at Istalef	07-15-07	1105	Shomali									
302	Panjshir River at Sayad	12-09-06	1155	Shomali									
302	Panjshir River at Sayad	12-26-06	1210	Shomali									
302	Panjshir River at Sayad	01-09-07	1115	Shomali									
302	Panjshir River at Sayad	01-23-07	1125	Shomali									
302	Panjshir River at Sayad	02-06-07	1130	Shomali		5.3		189.5	189.5	155	4.60	4.65	-0.24
302	Panjshir River at Sayad	02-20-07	1140	Shomali		5.7		197.6	197.6	162	4.98	4.96	0.11
302	Panjshir River at Sayad	03-06-07	1100	Shomali		5.7		176.0	176.0	144	4.92	4.57	1.85
302	Panjshir River at Sayad	03-20-07	0945	Shomali		3.5		113.0	113.0	93	2.71	2.67	0.35
302	Panjshir River at Sayad	04-03-07	1210	Shomali		3.3		100.0	100.0	82	2.31	2.32	-0.02
302	Panjshir River at Sayad	04-17-07	0855	Shomali		3.6		124.7	124.7	102	2.78	2.80	-0.13
302	Panjshir River at Sayad	06-19-07	1030	Shomali		3.3		112.6	112.6	92	2.63	2.70	-0.68
303	Barik Ab River	12-26-06	1030	Shomali									
303	Barik Ab River	01-09-07	1015	Shomali									
303	Barik Ab River	01-23-07	1240	Shomali									
303	Barik Ab River	02-20-07	1020	Shomali		8		439.8	439.8	361	16.44	15.41	1.62
303	Barik Ab River	03-06-07	1000	Shomali		5.4		211.0	211.0	173	8.50	8.56	-0.17

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Cl (mg/L)	SO_4 (mg/L)	F (mg/L)	Br (mg/L)	SiO_2 (mg/L)	ROE	SOC	ROESOC	Ion Balance Charge	Ion Balance Percent	ROESC	Al (µg/L)	Sb (µg/L)	As (µg/L)	As (µg/L) (R or D)
217	06-11-06															
218	06-20-06															
219	08-02-04	68	128	0.48	0.3	39	524						21.4	0.1		1.9
219	11-21-04	66.8	127	0.44	0.31	41	516	546	0.95	2.42	13.09	0.65	3.8	0.1		2
219	06-20-06	36.8	98.2	0.48	0.16	41.1		435		-0.61	-4.41		2	0.1	1.6	1.6
220	08-02-04	1,21.5	287	0.55	0.48	42	844						0.8	0.1		3.3
220	11-21-04	109	272	0.52	0.44	45	788					0.66	2.1	0.1		3.1
220	06-20-06															
221	12-05-06						635					0.55				0.9
221	02-19-07															
222	12-10-06						362					0.57				3.8
223	02-22-07	68.2	49.2	0.2	0.08	25.7							19	<0.1	1.4	1.4
301	12-04-06															
301	12-18-06															
301	01-02-07															
301	01-16-07															
301	01-30-07															
301	02-13-07	2.47	4.4	<0.05	<0.05	11.0							6	<0.1	0.6	0.6
301	02-27-07	1.92	4.8	0.07	<0.05	11.9							113	0.11	0.5	0.5
301	03-13-07	1.89	5.03	0.06	<0.05	12.3							140	<0.1	0.4	0.4
301	03-27-07	1.81	4.81	0.06	<0.05	11.7							53	<0.1	0.5	0.5
301	04-10-07	0.99	3.47	<0.05	<0.05	10.5							35	<0.1	0.4	0.4
301	04-24-07	0.82	2.89	<0.05	<0.05	9.3							12	<0.1	0.3	0.3
301	06-14-07	1.07	2.7	<0.05	<0.05	10.4							10	<0.1	0.4	0.4
301	07-15-07															
302	12-09-06															
302	12-26-06															
302	01-09-07															
302	01-23-07															
302	02-06-07	33.7	28.3	0.05	<0.05	7.9							26	0.2	1.2	1.2
302	02-20-07	37.5	31.6	0.06	<0.05	8.0							2	0.2	1.1	1.1
302	03-06-07	35.4	32.7	0.08	0.05	8.0							21	0.2	1	1
302	03-20-07	15.2	18.8	0.09	<0.05	8.0							28	0.2	1.8	1.8
302	04-03-07	11.4	17	0.08	<0.05	8.3							33	0.2	1.6	1.6
302	04-17-07	11.7	20.2	0.1	<0.05	7.8							29	0.2	1	1
302	06-19-07	14.1	22.1	0.06	<0.05	5.9							14	0.1	0.9	0.9
303	12-26-06															
303	01-09-07															
303	01-23-07															
303	02-20-07	149	192	0.3	<0.05	26.7							1,870	0.2	2.8	2.8
303	03-06-07	89.3	124	0.15	0.18	8.2							5	0.2	1.7	1.7

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Ba (µg/L)	Be (µg/L)	B (µg/L)	Cd (µg/L)	Cr (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L) D	Fe (µg/L)
217	Well 217	06-11-06	1100	Paghman/Upper Kabul									
218	Well 218	06-20-06	1030	Central Kabul									
219	Well 219	08-02-04	0000	Central Kabul	35	0.03	143	0.09	5.2	0.26	1.6	8.1	
219	Well 219	11-21-04	0000	Central Kabul	34	0.03	276	0.02	5.3	0.33	1.4	5	
219	Well 219	06-20-06	1000	Central Kabul	31		120	<0.05	4	0.27	1		<20
220	Well 220	08-02-04	0000	Central Kabul	43	0.03	231	0.02	3.9	0.44	2.8	13.1	
220	Well 220	11-21-04	0000	Central Kabul	40	0.03	232	0.02	4.4	2.91	1.6	4	
220	Well 220	06-20-06	1100	Central Kabul									
221	Well 221	12-05-06	1120	Logar		0.06							
221	Well 221	02-19-07	1120	Logar									
222	Afshar 6B	12-10-06	1220	Paghman/UpperKabul		0.06							
223	US Embassy CAFE well	02-22-07	1400	Central Kabul	89		690	<0.05	13	0.15	0.8		20
301	Istalef River at Istalef	12-04-06	1310	Shomali									
301	Istalef River at Istalef	12-18-06	0945	Shomali									
301	Istalef River at Istalef	01-02-07	1220	Shomali									
301	Istalef River at Istalef	01-16-07	1050	Shomali									
301	Istalef River at Istalef	01-30-07	1040	Shomali									
301	Istalef River at Istalef	02-13-07	1145	Shomali	19		30	<0.05	<1	0.42	0.2		<20
301	Istalef River at Istalef	02-27-07	1100	Shomali	20		<20	<0.05	<1	1.77	0.5		120
301	Istalef River at Istalef	03-13-07	1045	Shomali	18		<20	<0.05	<1	0.35	0.3		120
301	Istalef River at Istalef	03-27-07	1000	Shomali	14		<20	<0.05	<1	0.26	0.3		30
301	Istalef River at Istalef	04-10-07	0845	Shomali	10		<20	<0.05	<1	0.26	0.2		20
301	Istalef River at Istalef	04-24-07	1055	Shomali	8		<20	<0.05	<1	<0.05	0.3		<20
301	Istalef River at Istalef	06-14-07	0920	Shomali	14		<20	<0.05	<1	<0.05	1		<20
301	Istalef River at Istalef	07-15-07	1105	Shomali									
302	Panjshir River at Sayad	12-09-06	1155	Shomali									
302	Panjshir River at Sayad	12-26-06	1210	Shomali									
302	Panjshir River at Sayad	01-09-07	1115	Shomali									
302	Panjshir River at Sayad	01-23-07	1125	Shomali									
302	Panjshir River at Sayad	02-06-07	1130	Shomali	41		320	<0.05	<1	0.17	0.5		40
302	Panjshir River at Sayad	02-20-07	1140	Shomali	44		380	<0.05	<1	0.24	0.1		<20
302	Panjshir River at Sayad	03-06-07	1100	Shomali	40		400	<0.05	<1	0.46	0.1		<20
302	Panjshir River at Sayad	03-20-07	0945	Shomali	25		60	<0.05	<1	0.44	0.2		<20
302	Panjshir River at Sayad	04-03-07	1210	Shomali	23		40	<0.05	<1	0.33	0.3		<20
302	Panjshir River at Sayad	04-17-07	0855	Shomali	20		160	<0.05	<1	0.09	<0.1		<20
302	Panjshir River at Sayad	06-19-07	1030	Shomali	22		200	<0.05	<1	0.06	0.7		<20
303	Barik Ab River	12-26-06	1030	Shomali									
303	Barik Ab River	01-09-07	1015	Shomali									
303	Barik Ab River	01-23-07	1240	Shomali									
303	Barik Ab River	02-20-07	1020	Shomali	110		1,110	<0.05	6	1.72	4.6		2,280
303	Barik Ab River	03-06-07	1000	Shomali	58		490	<0.05	1	0.41	0.8		<20

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Pb (µg/L)	Li (µg/L)	Mn ICPMS µg/L	Mn (µg/L)	Mo (µg/L)	Ni (µg/L)	Se (µg/L)	Ag (µg/L)	Sr (µg/L)	Th (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)	Comment
217	06-11-06														
218	06-20-06														
219	08-02-04	0.11	14.6	0.6	0.7	3.7	0.93	2.6	0.1	1,160	0.02	4.85	17	16.1	FAFU
219	11-21-04	0.06	34.4	1.1	1	3.9	2.08	3.8	0.1	1,280	0.02	6.58	16.4	11.4	FAFU
219	06-20-06	0.12	13	2		3.9	0.5	3	<0.05	882		4.9	15	50	CFC,3H,FAFU
220	08-02-04	0.16	22	0.5	0.8	3.8	1.45	4	0.1	2,280	0.02	7.28	18.3	58.5	FAFU
220	11-21-04	0.04	21.1	3.8	4.2	3.7	2.08	4	0.1	2,010	0.02	8.05	18.4	7.7	FAFU
220	06-20-06														
221	12-05-06								0.1		0.04				3H,FAFU
221	02-19-07														CFC,DG
222	12-10-06								0.1		0.04				3H,FAFU
223	02-22-07	0.37	107	<1		1.3	7.8	<1	<0.05	779		5.84	3.4	42	3H,FAFU,CFC,DG
301	12-04-06														
301	12-18-06														
301	01-02-07														
301	01-16-07														
301	01-30-07														
301	02-13-07	<0.05	6	15		0.8	0.6	<1	<0.05	97		0.66	3	3	CFC,3H,FAFU
301	02-27-07	0.39	21	18		0.7	0.9	<1	<0.05	86		0.57	3.9	4	FAFU
301	03-13-07	0.1	20	13		0.6	0.6	<1	<0.05	82		0.57	3.5	<1	3H,FAFU
301	03-27-07	<0.05	17	6		0.6	0.8	<1	<0.05	66		0.5	3.7	<1	FAFU
301	04-10-07	0.06	12	4		0.5	0.4	<1	<0.05	480		0.33	3.3	9	3H,FAFU
301	04-24-07	0.08	11	2		0.4	0.6	<1	<0.05	38		0.24	2.5	1	FAFU, NFA
301	06-14-07	0.07	8	1		0.6	0.2	<1	<0.05	66		0.44	3.8	4	CFC,FAFU, NFA
301	07-15-07														CFC,FAFU
302	12-09-06														
302	12-26-06														
302	01-09-07														
302	01-23-07														
302	02-06-07	0.24	67	4		0.6	1.2	<1	<0.05	305		2.27	0.5	3	CFC,3H,FAFU
302	02-20-07	<0.05	78	4		0.7	1.2	<1	<0.05	328		2.37	0.5	3	FAFU
302	03-06-07	0.29	52	4		0.6	1.1	<1	<0.05	300		1.94	0.4	1	3H,FAFU
302	03-20-07	<0.05	33	5		0.9	1	<1	<0.05	149		1.59	0.8	<1	FAFU
302	04-03-07	<0.05	30	6		1.1	1	<1	<0.05	126		1.42	0.7	<1	3H,FAFU
302	04-17-07	<0.05	32	9		0.8	1	<1	<0.05	138		0.83	0.6	<1	FAFU
302	06-19-07	<0.05	47	2		0.8	0.5	<1	<0.05	153		0.91	1.3	4	CFC,FAFU, NFA
303	12-26-06														
303	01-09-07														
303	01-23-07														
303	02-20-07	1.67	109	64		3	6.2	3	<0.05	1920		17.5	10.9	8	CFC,3H,FAFU
303	03-06-07	<0.05	58	8		2	1.7	2	<0.05	783		6.96	2.6	2	FAFU

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Sample water level (m)	Water temperature (°C)	Spec. cond. (µS/cm)	Total dissolved solids	pH field	O_2 (mgL)	NO_2 N field (mg/L)	NO_3 N field (mg/L)	Total coli count per 100 mL
303	Barik Ab River	03-20-07	0830	Shomali		9.4	496	0.24	8.59		0	0-1	
303	Barik Ab River	04-03-07	1055	Shomali		9.2	114.3	0.08	8.54		0	1-2	
303	Barik Ab River	04-17-07	1000	Shomali		14.8	198	0.07	8.48		0	0-1	
303	Barik Ab River	05-20-07	0000	Shomali									
321	Logar River	12-05-06	1010	Logar		4.9	745	0.32	8.68		0	1-2	
321	Logar River	12-19-06	1040	Logar		4.1	746	0.29	8.75		0	1-2	
321	Logar River	01-06-07	0950	Logar		0.5	412.1	0.28	8.77		0-0.15	0-1	
321	Logar River	01-21-07	1050	Logar		0.7	412.7	0.32	8.63		0	0	
321	Logar River	02-07-07	1100	Logar		7.8	595	0.32	8.68		0	1-2	
321	Logar River	02-21-07	1055	Logar		6.2	754	0.13	8.77		0	1-2	1,120
321	Logar River	03-07-07	1000	Logar		9.1	704	0.33	8.78		0	0-1	
321	Logar River	03-19-07	0955	Logar		9.6	661	0.31	8.75		0	1-2	
321	Logar River	04-04-07	0955	Logar		11.2	510	0.25	8.64		0	0-1	
321	Logar River	04-18-07	1010	Logar		16.4	513	0.24	8.75		0	1-2	
321	Logar River	06-20-07	1110	Logar		22.2	1,215		8.64				
322	Kabul River at Tang-i-gharu	12-05-06	1320	Central Kabul		6.2	929	0.38	8.72		0.15-0.3	1-2	
322	Kabul River at Tang-i-gharu	12-25-06	1335	Central Kabul									
322	Kabul River at Tang-i-gharu	01-06-07	1225	Central Kabul		0.8	434.4	0.33	8.77		0-0.15	0-1	
322	Kabul River at Tang-i-gharu	01-21-07	1340	Central Kabul		4.2	748	0.31	8.86		0	0-1	
322	Kabul River at Tang-i-gharu	02-07-07	1300	Central Kabul		10	782	0.34	8.82		0	1-2	
322	Kabul River at Tang-i-gharu	02-21-07	1340	Central Kabul		7.8	742	0.21	8.89		0	1-2	>2,420
322	Kabul River at Tang-i-gharu	03-07-07	1000	Central Kabul		10.9	701	0.31	8.78		0	0-1	
322	Kabul River at Tang-i-gharu	03-19-07	1105	Central Kabul		8.8	510	0.23	8.68		0	1-2	
322	Kabul River at Tang-i-gharu	04-04-07	1200	Central Kabul		11.8	426	0.19	8.59		0	1-2	
322	Kabul River at Tang-i-gharu	04-18-07	1235	Central Kabul		16.9	365.5	0.17	8.64		0	1-2	
322	Kabul River at Tang-i-gharu	06-04-07	1115	Central Kabul		22.6	831		8.95				
322	Kabul River at Tang-i-gharu	07-04-07	0955	Central Kabul		22.9	810		8.76				
323	Paghman River at Paghman	12-10-06	1300	Paghman/Upper Kabul		8.5	142	0.05	9.03		0	0-1	
323	Paghman River at Paghman	12-25-06	1205	Paghman/Upper Kabul		3.7	126.3	0.04	9.02		0	1-2	
323	Paghman River at Paghman	01-10-07	1220	Paghman/Upper Kabul		4.6	127.8	0.04	8.92		0-0.15	0-1	

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month-day-year)	*E. coli* count per 100 mL	pH lab	Spec. cond. Lab (µS/cm)	NO_4 N (mg/L)	NO_2 N mg/L)	NO_2-NO_3N (mg/L)	NO_3 N (mg/L)	NO_3 NO_3 (mg/L)	Total N (mg/L)	PO_4 P (mg/L)	Ca (mg/L)	Mg (mg/L)	Hardness (mg/L)	Na (mg/L)
303	03-20-07							2.37	10.5			43.4	18.7		
303	04-03-07							2.00	8.85			22.8	6.1		32.6
303	04-17-07							1.36	6.04			20.5	5.6		8.95
303	05-20-07														8.67
321	12-05-06														
321	12-19-06														
321	01-06-07														
321	01-21-07							1.71	7.56			54.3	42.9		
321	02-07-07	162						1.87	8.3			55.6	41.6		42.1
321	02-21-07							1.71	7.59			54.2	38.8		44.8
321	03-07-07							2.39	10.6			50.2	23		42.6
321	03-19-07							3.37	14.9			50.1	21.7		23.1
321	04-04-07							2.37	10.5			49.1	22.7		23.7
321	04-18-07							1.36	6			48.3	71.8		22.6
321	06-20-07														97.2
322	12-05-06														
322	12-25-06														
322	01-06-07														
322	01-21-07														
322	02-07-07							2.33	10.3			56.1	43.5		47.1
322	02-21-07	>2,420						3.05	13.5			57.1	39.7		43.1
322	03-07-07							2.94	13			55.8	33.5		37.8
322	03-19-07							2.51	11.1			39.1	12.6		11.8
322	04-04-07							3.77	16.7			46.8	18.1		17.7
322	04-18-07							2.39	10.6			39.9	13.7		12.6
322	06-04-07							3.89	17.2			60.5	32.2		59.7
322	07-04-07							2.94	13			60.6	39.6		46.3
323	12-10-06														
323	12-25-06														
323	01-10-07														

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	SAR	K (mg/L)	Alk mg/L as $CaCO_3$ (D)	Alk mg/L as HCO_3 (R)	Alk mg/L as HCO_3 (R&D)	Alk mg/L as $CaCO_3$ R&D	sum meq cations	sum meq anions	Percent charge imbalance
303	Barik Ab River	03-20-07	0830	Shomali					0.0				
303	Barik Ab River	04-03-07	1055	Shomali		4.4		173.4	173.4	142	5.30	5.21	0.43
303	Barik Ab River	04-17-07	1000	Shomali		2.8		90.3	90.3	74	2.12	2.04	0.96
303	Barik Ab River	05-20-07	0000	Shomali		2.5		78.5	78.5	64	1.94	1.90	0.60
321	Logar River	12-05-06	1010	Logar									
321	Logar River	12-19-06	1040	Logar									
321	Logar River	01-06-07	0950	Logar									
321	Logar River	01-21-07	1050	Logar									
321	Logar River	02-07-07	1100	Logar		3.8		348.4	348.4	286	8.32	7.88	1.35
321	Logar River	02-21-07	1055	Logar		3.8		359.7	359.7	295	8.39	8.37	0.07
321	Logar River	03-07-07	1000	Logar		3.6		327.7	327.7	269	7.98	7.51	1.50
321	Logar River	03-19-07	0955	Logar		3		260.4	260.4	214	5.56	5.46	0.44
321	Logar River	04-04-07	0955	Logar		4		243.4	243.4	200	5.50	5.29	0.96
321	Logar River	04-18-07	1010	Logar		2.8		260.4	260.4	214	5.45	5.45	0.00
321	Logar River	06-20-07	1110	Logar		6.5		470.9	470.9	386	12.97	13.12	-0.30
322	Kabul River at Tang-i-gharu	12-05-06	1320	Central Kabul									
322	Kabul River at Tang-i-gharu	12-25-06	1335	Central Kabul									
322	Kabul River at Tang-i-gharu	01-06-07	1225	Central Kabul									
322	Kabul River at Tang-i-gharu	01-21-07	1340	Central Kabul									
322	Kabul River at Tang-i-gharu	02-07-07	1300	Central Kabul		4.4		359.0	359.0	294	8.69	8.49	0.59
322	Kabul River at Tang-i-gharu	02-21-07	1340	Central Kabul		4.4		348.6	348.6	286	8.24	8.13	0.34
322	Kabul River at Tang-i-gharu	03-07-07	1000	Central Kabul		4		329.3	329.3	270	7.41	7.50	-0.31
322	Kabul River at Tang-i-gharu	03-19-07	1105	Central Kabul		2.3		170.9	170.9	140	3.60	3.50	0.75
322	Kabul River at Tang-i-gharu	04-04-07	1200	Central Kabul		3.7		202.7	202.7	166	4.75	4.39	1.99
322	Kabul River at Tang-i-gharu	04-18-07	1235	Central Kabul		2.3		181.7	181.7	149	3.77	3.74	0.20
322	Kabul River at Tang-i-gharu	06-04-07	1115	Central Kabul		6.7		279.6	279.6	229	8.55	8.43	0.35
322	Kabul River at Tang-i-gharu	07-04-07	0955	Central Kabul		5.6		357.3	357.3	293	8.58	8.49	0.26
323	Paghman River at Paghman	12-10-06	1300	Paghman/Upper Kabul									
323	Paghman River at Paghman	12-25-06	1205	Paghman/Upper Kabul									
323	Paghman River at Paghman	01-10-07	1220	Paghman/Upper Kabul									

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/day/year)	Cl (mg/L)	SO_4 (mg/L)	F (mg/L)	Br (mg/L)	SiO_2 (mg/L)	ROE	SOC	ROESOC	Ion Balance Charge	Ion Balance Percent	ROESC	Al (µg/L)	Sb (µg/L)	As (µg/L)	As (µg/L) (R or D)
303	03-20-07															
303	04-03-07	35.9	65.1	0.2	0.09	11.8							34	0.3	2.4	2.4
303	04-17-07	8.46	15.5	0.1	<0.05	11.7							102	<0.1	1.6	1.6
303	05-20-07	9.79	16.1	0.07	<0.05	9.0							19	<0.1	1.2	1.2
321	12-05-06															
321	12-19-06															
321	01-06-07															
321	01-21-07															
321	02-07-07	39.3	51	0.3	0.07	15.9							14	0.2	2.4	2.4
321	02-21-07	42.3	61.3	0.32	0.08	15.9							49	0.2	2.7	2.7
321	03-07-07	37.8	51.6	0.29	0.09	15.7							129	0.2	2.4	2.4
321	03-19-07	18.7	32	0.23	<0.05	12.7							25	0.2	2.7	2.7
321	04-04-07	19.1	36.5	0.23	0.05	13.8							380	0.4	3.5	3.5
321	04-18-07	18.5	31.8	0.23	<0.05	12.6							13	0.2	3	3
321	06-20-07	108	113	0.36	0.19	21.6							20	0.2	4.4	4.4
322	12-05-06															
322	12-25-06															
322	01-06-07															
322	01-21-07															
322	02-07-07	46.2	62.5	0.31	0.06	16.4							6	0.2	3.2	3.2
322	02-21-07	43	57.8	0.28	0.09	15.8							81	0.2	3.1	3.1
322	03-07-07	36.8	51	0.25	0.08	14.4							7	0.3	3.5	3.5
322	03-19-07	10.5	19.2	0.13	<0.05	10.7							23	0.2	2.8	2.8
322	04-04-07	15.8	29.8	0.19	<0.05	17.8							1,260	0.2	2.3	2.3
322	04-18-07	11.3	21.4	0.15	<0.05	10.7							11	0.1	2.2	2.2
322	06-04-07	70	89.9	0.2	0.15	9.1							20	0.3	8.3	8.3
322	07-04-07	46.7	63.2	0.23	0.11	19.2							10	0.2	5.5	5.5
323	12-10-06															
323	12-25-06															
323	01-10-07															

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Ba (µg/L)	Be (µg/L)	B (µg/L)	Cd (µg/L)	Cr (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L)	D	Fe (µg/L)
303	Barik Ab River	03-20-07	0830	Shomali										
303	Barik Ab River	04-03-07	1055	Shomali	43		330	<0.05	<1	1.02	0.5			<20
303	Barik Ab River	04-17-07	1000	Shomali	22		80	<0.05	<1	0.26	0.3			30
303	Barik Ab River	05-20-07	0000	Shomali	19		80	<0.05	<1	0.08	0.6			<20
321	Logar River	12-05-06	1010	Logar										
321	Logar River	12-19-06	1040	Logar										
321	Logar River	01-06-07	0950	Logar										
321	Logar River	01-21-07	1050	Logar										
321	Logar River	02-07-07	1100	Logar	51		690	<0.05	2	1.11	0.5			<20
321	Logar River	02-21-07	1055	Logar	51		710	<0.05	3	0.97	0.6			<20
321	Logar River	03-07-07	1000	Logar	50		640	<0.05	2	1.85	1			150
321	Logar River	03-19-07	0955	Logar	32		380	<0.05	<1	1.82	1			20
321	Logar River	04-04-07	0955	Logar	53		590	<0.05	2	2.38	2.2			440
321	Logar River	04-18-07	1010	Logar	34		420	<0.05	<1	0.19	1.2			<20
321	Logar River	06-20-07	1110	Logar	58		1,290	<0.05	4	0.39	2.1			60
322	Kabul River at Tang-i-gharu	12-05-06	1320	Central Kabul										
322	Kabul River at Tang-i-gharu	12-25-06	1335	Central Kabul										
322	Kabul River at Tang-i-gharu	01-06-07	1225	Central Kabul										
322	Kabul River at Tang-i-gharu	01-21-07	1340	Central Kabul										
322	Kabul River at Tang-i-gharu	02-07-07	1300	Central Kabul	52		730	<0.05	2	0.76	0.8			<20
322	Kabul River at Tang-i-gharu	02-21-07	1340	Central Kabul	51		660	<0.05	2	1.55	1			<20
322	Kabul River at Tang-i-gharu	03-07-07	1000	Central Kabul	47		670	<0.05	1	1.7	1.2			<20
322	Kabul River at Tang-i-gharu	03-19-07	1105	Central Kabul	15		200	<0.05	<1	0.79	0.6			<20
322	Kabul River at Tang-i-gharu	04-04-07	1200	Central Kabul	30		240	<0.05	3	1.74	2.4			1,690
322	Kabul River at Tang-i-gharu	04-18-07	1235	Central Kabul	14		180	<0.05	<1	0.13	0.6			<20
322	Kabul River at Tang-i-gharu	06-04-07	1115	Central Kabul	48		570	<0.05	3	0.82	4.3			<20
322	Kabul River at Tang-i-gharu	07-04-07	0955	Central Kabul	57		700	<0.05	2	0.81	1.7			<20
323	Paghman River at Paghman	12-10-06	1300	Paghman/Upper Kabul										
323	Paghman River at Paghman	12-25-06	1205	Paghman/Upper Kabul										
323	Paghman River at Paghman	01-10-07	1220	Paghman/Upper Kabul										

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Pb (µg/L)	Li (µg/L)	Mn ICPMS µg/L	Mn (µg/L)	Mo (µg/L)	Ni (µg/L)	Se (µg/L)	Ag (µg/L)	Sr (µg/L)	Th (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)	Comment
303	03-20-07														
303	04-03-07	<0.05	43	24		2.8	2.3	1	<0.05	578		4.78	5.3	<1	FAFU
303	04-17-07	0.07	23	14		1.2	0.9	<1	<0.05	177		1.7	5.3	<1	FAFU
303	05-20-07	0.21	21	10		0.9	0.7	<1	<0.05	145		1.4	4.2	<1	FAFU
321	12-05-06														
321	12-19-06														
321	01-06-07														
321	01-21-07														
321	02-07-07	<0.05	143	13		2.7	2.8	1	<0.05	667		4.37	2.6	2	CFC,3H,FAFU
321	02-21-07	0.07	142	11		3.4	3.3	3	<0.05	707		5.33	2.5	2	FAFU
321	03-07-07	0.14	134	13		2.8	3.8	2	0.07	623		4.01	2.6	2	3H,FAFU
321	03-19-07	<0.05	69	7		2.2	2.9	2	<0.05	353		2.41	2.3	2	FAFU
321	04-04-07	0.57	107	37		3.5	7.6	1	<0.05	345		4.34	4.9	4	3H,FAFU
321	04-18-07	<0.05	74	3		2.4	4.1	<1	<0.05	347		2.62	2.5	1	FAFU
321	06-20-07	0.26	224	44		3.7	4.3	2	<0.05	1,460		8.78	4.7	9	CFC,FAFU, NFA
322	12-05-06														
322	12-25-06														
322	01-06-07														
322	01-21-07														
322	02-07-07	<0.05	136	16		3.3	3.3	2	<0.05	715		5.07	2.9	1	CFC,3H,FAFU
322	02-21-07	0.14	124	25		2.8	4.1	2	<0.05	652		4.64	3.1	2	FAFU
322	03-07-07	<0.05	117	28		2.6	4.6	<1	<0.05	543		3.79	3.1	4	3H,FAFU
322	03-19-07	<0.05	32	13		1.3	2.2	<1	<0.05	202		1.4	1.8	<1	FAFU
322	04-04-07	1.25	42	67		0.9	11	<1	<0.05	285		2.15	4.3	5	3H,FAFU
322	04-18-07	<0.05	29	6		1.2	2.3	<1	<0.05	220		1.34	1.6	<1	FAFU
322	06-04-07	0.16	79	57		3.1	3.8	2	<0.05	689		3.78	6.3	2	CFC,FAFU, NFA
322	07-04-07	0.14	131	84		2.7	3.2	2	<0.05	643		3.9	5.8	2	SCFC,FAFU, NFA
323	12-10-06														
323	12-25-06														
323	01-10-07														

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	Sample water level (m)	Water tempe-rature (°C)	Spec. cond. (µS/cm)	Total dissolved solids	pH field	O_2 (mgL)	NO_2 N field (mg/L)	NO_3 N field (mg/L)	Total coli count per 100 mL
323	Paghman River at Paghman	01-25-07	1130	Paghman/Upper Kabul		7.5	140.3	0.05	9.02		0	0-1	
323	Paghman River at Paghman	02-10-07	1350	Paghman/Upper Kabul		5.7	111	0.04	8.96		0	0-1	
323	Paghman River at Paghman	02-24-07	1245	Paghman/Upper Kabul		6.3	109.8	0.04	8.91		0	0-1	116
323	Paghman River at Paghman	03-10-07	1225	Paghman/Upper Kabul		7.7	106	0.03	8.66		0	0-1	
323	Paghman River at Paghman	03-24-07	1215	Paghman/Upper Kabul		12.3	101	0.03	8.52		0	0-1	
323	Paghman River at Paghman	04-07-07	1230	Paghman/Upper Kabul		11.8	80.9	0.03	8.6		0	1-2	
323	Paghman River at Paghman	04-21-07	1145	Paghman/Upper Kabul		13.8	67.4	0.03	8.7		0	0-1	
323	Paghman River at Paghman	06-02-07	1030	Paghman/Upper Kabul		18	98.5		8.64				
323	Paghman River at Paghman	07-02-07	1005	Paghman/Upper Kabul		18	114	0.03	8.41		0	0-1	
324	Kabul River at Tangi Saedan	12-10-06	1020	Paghman/Upper Kabul		5.5	786	0.32	8.39		0.15-0.3	0-1	
324	Kabul River at Tangi Saedan	12-25-06	1045	Paghman/Upper Kabul		14.7	678	0.3	8.45		0-0.15	1-2	
324	Kabul River at Tangi Saedan	01-10-07	0955	Paghman/Upper Kabul		2.7	663	0.29	8.4		0-0.15	1-2	
324	Kabul River at Tangi Saedan	01-25-07	1010	Paghman/Upper Kabul		6.3	666	0.28	8.36		0	1-2	
324	Kabul River at Tangi Saedan	02-10-07	1100	Paghman/Upper Kabul		6.9	553	0.25	8.57		0	0-1	
324	Kabul River at Tangi Saedan	02-24-07	1130	Paghman/Upper Kabul		6.3	508	0.21	8.51		0	1-2	1,414
324	Kabul River at Tangi Saedan	03-10-07	0900	Paghman/Upper Kabul		6.4	394.7	0.18	8.28		0	0-1	
324	Kabul River at Tangi Saedan	03-24-07	1040	Paghman/Upper Kabul		8.1	326.2	0.13	8.63		0	1-2	
324	Kabul River at Tangi Saedan	04-07-07	1010	Paghman/Upper Kabul		11.2	277.3	0.13	8.49		0	1-2	
324	Kabul River at Tangi Saedan	04-21-07	1015	Paghman/Upper Kabul		11.4	293.3	0.11	8.48		0	1-2	
987	Panjshir River at Shukhi	05-11-06	0000	Shomali									

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month-day-year)	*E. coli* count per 100 mL	pH lab	Spec. cond. Lab (µS/cm)	NO_4 N (mg/L)	NO_2 N mg/L)	NO_2- NO_3N (mg/L)	NO_3 N (mg/L)	NO_3 NO_3 (mg/L)	Total N (mg/L)	PO_4 P (mg/L)	Ca (mg/L)	Mg (mg/L)	Hardness (mg/L)	Na (mg/L)
323	01-25-07														
323	02-10-07							0.98	4.32			14.9	2.1		3.28
323	02-24-07	42.2						0.97	4.28			15.2	2.04		3.3
323	03-10-07							1.13	4.99			13.8	1.9		3
323	03-24-07							0.96	4.27			8.07	1.41		2.07
323	04-07-07							1.36	6.01			10.2	1.54		2.06
323	04-21-07							0.93	4.12			8.79	1.58		2.18
323	06-02-07							0.40	1.78			13.9	2.04		3.12
323	07-02-07							0.61	2.71			16.3	2.12		3.13
324	12-10-06														
324	12-25-06														
324	01-10-07														
324	01-25-07														
324	02-10-07							2.51	11.1			72.4	22.2		19.9
324	02-24-07	387						2.62	11.6			65.3	17.9		15.2
324	03-10-07							3.32	14.7			53.7	12.7		10.1
324	03-24-07							2.14	9.49			35.5	6.88		5.16
324	04-07-07							2.69	11.9			41.9	8.83		6.62
324	04-21-07							2.37	10.5			40.3	8.33		6.1
987	05-11-06							0.82	3.63			26.7	5.34	88.7	7.72

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month-day-year)	Time (hhmm)	Sub basin or source water area	SAR	K (mg/L)	Alk mg/L as $CaCO_3$ (D)	Alk mg/L as HCO_3 (R)	Alk mg/L as HCO_3 (R&D)	Alk mg/L as $CaCO_3$ R&D	sum meq cations	sum meq anions	Percent charge imbalance
323	Paghman River at Paghman	01-25-07	1130	Paghman/Upper Kabul									
323	Paghman River at Paghman	02-10-07	1350	Paghman/Upper Kabul		0.9		51.3	51.3	42	1.09	1.04	1.27
323	Paghman River at Paghman	02-24-07	1245	Paghman/Upper Kabul		0.9		51.7	51.7	42	1.10	1.04	1.30
323	Paghman River at Paghman	03-10-07	1225	Paghman/Upper Kabul		0.8		48.3	48.3	40	1.00	0.99	0.34
323	Paghman River at Paghman	03-24-07	1215	Paghman/Upper Kabul		1.1		27.8	27.8	23	0.64	0.57	2.87
323	Paghman River at Paghman	04-07-07	1230	Paghman/Upper Kabul		0.8		32.6	32.6	27	0.75	0.67	2.82
323	Paghman River at Paghman	04-21-07	1145	Paghman/Upper Kabul		0.9		30.2	30.2	25	0.69	0.63	2.34
323	Paghman River at Paghman	06-02-07	1030	Paghman/Upper Kabul		1.2		51.3	51.3	42	1.04	1.00	0.97
323	Paghman River at Paghman	07-02-07	1005	Paghman/Upper Kabul		1.4		59.3	59.2	49	1.17	1.12	0.98
324	Kabul River at Tangi Saedan	12-10-06	1020	Paghman/Upper Kabul									
324	Kabul River at Tangi Saedan	12-25-06	1045	Paghman/Upper Kabul									
324	Kabul River at Tangi Saedan	01-10-07	0955	Paghman/Upper Kabul									
324	Kabul River at Tangi Saedan	01-25-07	1010	Paghman/Upper Kabul									
324	Kabul River at Tangi Saedan	02-10-07	1100	Paghman/Upper Kabul		3.4		316.8	316.8	260	6.47	6.17	1.18
324	Kabul River at Tangi Saedan	02-24-07	1130	Paghman/Upper Kabul		2.5		283.3	283.3	232	5.52	5.44	0.36
324	Kabul River at Tangi Saedan	03-10-07	0900	Paghman/Upper Kabul		1.9		217.9	217.9	179	4.26	4.15	0.63
324	Kabul River at Tangi Saedan	03-24-07	1040	Paghman/Upper Kabul		1.7		135.3	135.3	111	2.63	2.53	1.00
324	Kabul River at Tangi Saedan	04-07-07	1010	Paghman/Upper Kabul		1.6		158.8	158.8	130	3.18	3.00	1.41
324	Kabul River at Tangi Saedan	04-21-07	1015	Paghman/Upper Kabul		1.5		155.0	155.0	127	3.03	2.90	1.09
987	Panjshir River at Shukhi	05-11-06	0000	Shomali	0.36	2.9	97.2	97.2	97.2	80	2.20	2.18	0.22

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Cl (mg/L)	SO_4 (mg/L)	F (mg/L)	Br (mg/L)	SiO_2 (mg/L)	ROE	SOC	ROESOC	Ion Balance Charge	Ion Balance Percent	ROESC	Al (µg/L)	Sb (µg/L)	As (µg/L)	As (µg/L) (R or D)
323	01-25-07															
323	02-10-07	2.24	6.3	<0.05	<0.05	6.9							4	<0.1	0.4	0.4
323	02-24-07	2.31	6.32	<0.05	<0.05	6.7							36	0.1	0.4	0.4
323	03-10-07	2.01	6.75	0.06	<0.05	7.0							4	<0.1	0.5	0.5
323	03-24-07	0.93	4.33	<0.05	<0.05	6.7							81	<0.1	0.7	0.7
323	04-07-07	1.2	4.93	<0.05	<0.05	8.2							145	<0.1	0.6	0.6
323	04-21-07	1.41	4.57	<0.05	<0.05	7.0							11	<0.1	0.8	0.8
323	06-02-07	1.51	5.39	<0.05	<0.05	8.5							15	<0.1	0.7	0.7
323	07-02-07	1.38	5.38	<0.05	<0.05	9.5							17	0.3	0.8	0.8
324	12-10-06															
324	12-25-06															
324	01-10-07															
324	01-25-07															
324	02-10-07	21.9	17.3	0.12	<0.05	14.9							190	0.1	4.6	4.6
324	02-24-07	16.5	15.9	0.12	<0.05	13.5							7	0.1	4.1	4.1
324	03-10-07	9.78	14.6	0.12	<0.05	12.3							11	0.2	2.7	2.7
324	03-24-07	4.16	9.18	0.08	<0.05	9.4							37	0.2	1.8	1.8
324	04-07-07	5.76	11.4	0.09	<0.05	11.0							10	0.1	1.8	1.8
324	04-21-07	5.3	10.1	0.08	<0.05	9.9							20	<0.1	2	2
987	05-11-06	9.9	14.8	0.07	<0.05	6.5				-0.41	-8.52		17	0.1	0.8	0.8

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month/ day/year)	Time (hhmm)	Sub basin or source water area	Ba (µg/L)	Be (µg/L)	B (µg/L)	Cd (µg/L)	Cr (µg/L)	Co (µg/L)	Cu (µg/L)	Fe (µg/L) D	Fe (µg/L)
323	Paghman River at Paghman	01-25-07	1130	Paghman/Upper Kabul									
323	Paghman River at Paghman	02-10-07	1350	Paghman/Upper Kabul	5		30	<0.05	<1	0.59	<0.1		<20
323	Paghman River at Paghman	02-24-07	1245	Paghman/Upper Kabul	5		20	<0.05	<1	2.07	<0.1		40
323	Paghman River at Paghman	03-10-07	1225	Paghman/Upper Kabul	5		<20	<0.05	<1	0.56	0.5		<20
323	Paghman River at Paghman	03-24-07	1215	Paghman/Upper Kabul	3		<20	<0.05	<1	1.48	0.5		60
323	Paghman River at Paghman	04-07-07	1230	Paghman/Upper Kabul	4		<20	<0.05	<1	0.18	0.5		154
323	Paghman River at Paghman	04-21-07	1145	Paghman/Upper Kabul	3		<20	<0.05	<1	<0.05	0.5		<20
323	Paghman River at Paghman	06-02-07	1030	Paghman/Upper Kabul	5		40	<0.05	<1	<0.05	1		<20
323	Paghman River at Paghman	07-02-07	1005	Paghman/Upper Kabul	6		30	1.17	<1	0.06	1		<20
324	Kabul River at Tangi Saedan	12-10-06	1020	Paghman/Upper Kabul									
324	Kabul River at Tangi Saedan	12-25-06	1045	Paghman/Upper Kabul									
324	Kabul River at Tangi Saedan	01-10-07	0955	Paghman/Upper Kabul									
324	Kabul River at Tangi Saedan	01-25-07	1010	Paghman/Upper Kabul									
324	Kabul River at Tangi Saedan	02-10-07	1100	Paghman/Upper Kabul	38		480	<0.05	1	1.29	0.2		170
324	Kabul River at Tangi Saedan	02-24-07	1130	Paghman/Upper Kabul	29		350	<0.05	<1	0.5	<0.1		<20
324	Kabul River at Tangi Saedan	03-10-07	0900	Paghman/Upper Kabul	24		30	<0.05	<1	0.91	0.4		<20
324	Kabul River at Tangi Saedan	03-24-07	1040	Paghman/Upper Kabul	8		<20	<0.05	<1	0.88	0.4		20
324	Kabul River at Tangi Saedan	04-07-07	1010	Paghman/Upper Kabul	8		<20	<0.05	<1	0.16	0.3		<20
324	Kabul River at Tangi Saedan	04-21-07	1015	Paghman/Upper Kabul	9		<20	<0.05	<1	0.11	0.4		<20
987	Panjshir River at Shukhi	05-11-06	0000	Shomali	79		120	<0.05	<1	<0.05	0.5		<20

Table 10-1A. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	Pb (µg/L)	Li (µg/L)	Mn ICPMS µg/L	Mn (µg/L)	Mo (µg/L)	Ni (µg/L)	Se (µg/L)	Ag (µg/L)	Sr (µg/L)	Th (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)	Comment
323	01-25-07														
323	02-10-07	<0.05	1	4		0.4	0.6	<1	<0.05	58		0.2	0.6	2	CFC,3H,FAFU
323	02-24-07	0.07	<1	7		0.3	0.8	<1	<0.05	57		0.16	0.6	2	FAFU
323	03-10-07	<0.05	<1	4		0.3	0.7	<1	<0.05	49		0.09	0.5	<1	3H,FAFU
323	03-24-07	0.06	1	14		0.3	0.7	<1	<0.05	32		0.06	0.5	2	FAFU
323	04-07-07	0.1	<1	4		0.3	0.6	<1	<0.05	36		0.06	1	2	3H,FAFU
323	04-21-07	<0.05	0	2		0.3	0.4	<1	<0.05	33		0.06	0.6	3	FAFU
323	06-02-07	0.15	4	1		0.4	0.2	<1	<0.05	50		0.12	1.5	1	CFC,FAFU, NFA
323	07-02-07	0.13	4	3		0.4	0.2	<1	<0.05	59		0.14	1.8	12	CFC,FAFU, NFA
324	12-10-06														
324	12-25-06														
324	01-10-07														
324	01-25-07														
324	02-10-07	0.026	65	50		0.6	5.8	<1	<0.05	397		1.93	2.1	2	CFC,3H,FAFU
324	02-24-07	<0.05	48	31		0.7	4.1	<1	<0.05	335		1.63	1.5	1	FAFU
324	03-10-07	<0.05	26	44		1	4	<1	<0.05	239		1.23	1.7	<1	FAFU
324	03-24-07	<0.05	11	6		0.7	1.5	<1	<0.05	127		0.59	0.6	<1	FAFU
324	04-07-07	<0.05	14	5		0.7	2	<1	<0.05	161		0.66	0.5	<1	FAFU
324	04-21-07	0.05	14	7		0.6	1.7	<1	<0.05	152		0.65	0.6	<1	FAFU
987	05-11-06	<0.05	21	<1		0.8	0.3	<1	<0.05	128		0.91	0.5	21	3H,FAFU

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Appendix 10. Water-Quality Data—Continued

Appendix 10-1B. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan

[°C, degrees Celsius; mg/L, milligrams per liter; samples analyzed at USGS laboratory; --, not applicable; pg/kg, picogram per kilogram water]

Table 10-1B Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month/day/year)	Time (hhmm)	Subbasin or source water area	Water temperature (°C)	Delta 2H x1000	Delta 18O x1000	Tritium TU	Tritium Plus Minus	CFC11 (pg/kg)	CFC12 (pg/kg)
2.1	Well 2.1	06-07-06	0945	Eastern Front	20.5	-58.9	-9.7				
6	Karez N6	05-10-06	1140	Eastern Front	16.3	-54	-9.04				
7	Well 7	06-04-06	0945	Eastern Front	12.6	-48.8	-8.78				
8	Well 8	06-07-06	1025	Deh Sabz	17.4	-55	-8.29				
10	Karez 10	05-10-06	1205	Eastern Front		-54.6	-9.23				
13	Well 13	05-16-06	1200	Deh Sabz	20.1	-56.6	-8.98	16.7	0.5	246	185
15	Well 15	05-30-06	1510	Deh Sabz	15.8	-52.4	-8.02				
20	Well 20	06-10-06	0925	Western Front	13.2	-45.8	-8.16				
21	Well 21	06-12-06	0920	Western Front	14	-53.1	-9.01				
22.1	Well 22.1	06-12-06	0945	Shomali	14.1	-47.9	-8.11				
24	Well 24	06-14-06	0950	Shomali	15.5	-50.1	-8.47				
25	Well 25	06-14-06	1015	Shomali	15.8	-52.8	-8.55				
28	Well 28	05-23-06	1300	Shomali	13.7	-52.4	-8.49	15.8	0.5	424	219
33	Well 33	05-23-06	1030	Western Front	16.3	-49.5	-8.43	20.1	0.6	203	142
37	Well 37	05-14-06	1000	Deh Sabz	18.8	-63	-9.69	0.87	0.13	195	134
41	Well 41	05-28-06	0950	Western Front	18.1	-50.2	-8.7				
42	Well 42	05-28-06	0810	Shomali	15.8	-55.8	-9.08	8.29	0.28	309	172
43	Well 43	05-28-06	0925	Western Front	15.2	-52.3	-8.9				
45	Well 45	05-30-06	1220	Western Front	18.2	-56.2	-9.29				
47	Well 47	05-30-06	1345	Shomali	16.1	-53.7	-8.62	8.41	0.28	447	234
52	Well 52	06-10-06	1030	Western Front	13.8	-45.7	-8.15				
54	Well 54	05-21-06	1145	Deh Sabz	18.2	-59.1	-9.03	5.08	0.21	128	77
59.1	Well 59.1	05-10-06	1005	Eastern Front	17.7	-55.2	-9.3	5.25	0.22	245	204
64	Well 64	06-24-06	0830	Central Kabul	16.9	-55.9	-8.87				
65	Well 65	05-25-06	0930	Central Kabul	21.6	-60.7	-9.28	9.0	0.3	195	108
66.1	Spring 66.1	05-10-06	1110	Eastern Front	15.3	-50.5	-8.85	12.7	0.4	322	232
67	Well 67	12-09-06	1300	Western Front	14.5	-56.9	-9.34	11.8	0.4		
67.1	Kheelre Spring	05-23-06	1145	Shomali	16.7	-49.9	-8.24	18.0	0.5	383	248
67.2	Spring 67A	06-17-06	1120	Shomali	18.6	-51.7	-8.53				
68.1	Spring 68	05-21-06	1000	Shomali	14.9	-50.1	-8.38	16.3	0.5	473	225
69.1	Karez 69.1	05-10-06	1030	Eastern Front	18.3	-50	-8.72				
71	Azizi Hotak Tank	06-05-07	0940	Eastern Front	20	-56.5	-9.46	0.41	0.17	220	157
72	Well 72	06-12-07	0900	Shomali	15.2	-50	-8.39	17.4	0.5	600	233
73	9 Pola Qare Bagh	06-17-07	1015	Western Front	16.3	-55	-9.18	8.64	0.27	232	122
74	Well 74	06-19-07	1140	Shomali	15.2	-57.5	-9.17	10.4	0.4	471	279
100	Swedish well 224	06-03-06	1100	Western Front	13.2	-46.8	-8.19				
101	Spring 101	05-13-06	1130	Western Front	11	-45.9	-8.16	11.0	0.3	752	360
104	Well 104	05-13-06	1100	Western Front	14.4	-50.3	-8.46	7.56	0.25	491	251
104	Well 104	12-03-06	1220	Western Front	12.1	-48.3	-8.34	13.1	0.4		
105	Karez 105	05-13-06	1000	Paghman/Upper Kabul	14.7	-41.9	-6.94	11.4	0.3	364	221
107	Well 107	05-15-06	1040	Paghman/Upper Kabul	15.5	-59.8	-9.29	6.78	0.22	191	99.5
112	Well 112	06-03-06	1200	Paghman/Upper Kabul	16.2	-55.3	-8.47				
113	Well 113	05-29-06	0930	Paghman/Upper Kabul	15.4	-56.2	-8.84				
115	Well 115	05-29-06	1015	Paghman/Upper Kabul	19.5	-47.5	-8.43				
116	Well 116	05-29-06	1105	Logar	15.9	-54.7	-8.58				
117	Well 117	05-15-06	1220	Paghman/Upper Kabul	16.6	-53.1	-8.48	15.2	0.5	440	252
124	Well 124	05-27-06	0900	Central Kabul	14.5	-56.1	-8.87				
129	Well 129	05-24-06	1255	Central Kabul	17.6	-55.6	-8.79	15.0	0.5	437	539
133	Well 133	05-27-06	0930	Central Kabul	16.2	-55	-8.52				
135	Well 135	05-17-06	1050	Logar	15.3	-53.9	-8.28	15.90	0.50	396	221
140	Well 140	05-29-06	1220	Logar	15.8	-54.7	-8.18				
143	Well 143	05-29-06	1200	Logar	14.5	-55.3	-8.27				

Table 10-1B. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	CFC113 (pg/kg)	Percent Modern CFC11	Percent Modern CFC12	Percent Modern CFC113	N_2 dissolved (mg/L)	Ar dissolved (mg/L)	O_2 dissolved (mg/L)	CO_2 dissolved (mg/L)	CH_4 dissolved (mg/L)	He dissolved cc_STP_g H20x10_9	H_2 dissolved cc_STP_g H20x10_9	Ne dissolved cc_STP_g H20x10_9
2.1	06-07-06												
6	05-10-06												
7	06-04-06												
8	06-07-06												
10	05-10-06												
13	05-16-06	29.6	49.9	73.1	45.5								
15	05-30-06												
20	06-10-06												
21	06-12-06												
22.1	06-12-06												
24	06-14-06												
25	06-14-06												
28	05-23-06	55.6	84.8	85.3	84.5								
33	05-23-06	20.3	41.6	57	31.6	16.5	0.559	0.167	24.5	0.0000	45.4	13	186.5
37	05-14-06	32.8	38.8	52.1	49.6								
41	05-28-06												
42	05-28-06	38.6	60.6	65.8	57.6								
43	05-28-06												
45	05-30-06												
47	05-30-06	54.2	87.2	89.3	80.3								
52	06-10-06												
54	05-21-06	16.5	25.9	30.5	25.4	13.8	0.481	1.91	14.7	0.0000	592.6	22.2	230.7
59.1	05-10-06	47.2	49.8	81.1	72.8								
64	06-24-06												
65	05-25-06	21.9	39.8	43.1	34.1								
66.1	05-10-06	41.7	62.1	88.5	60.9								
67	12-09-06												
67.1	05-23-06	48.5	73.9	94.2	70.8								
67.2	06-17-06												
68.1	05-21-06	59.5	91.3	85.7	86.9								
69.1	05-10-06												
71	06-05-07	36.1	50	70.3	63.8	19.3	0.579	0.136	22.1	0.0000			
72	06-12-07	61.9	114	88.5	89.5	15.8	0.542	0.131	23.5	0.0000			
73	06-17-07	28	40.6	42.5	36.9	17.8	0.585	0.152	11.5	0.0000			
74	06-19-07	68.6	83.2	98.2	91.5	16.1	0.576	0.321	38.5	0.0000			
100	06-03-06												
101	05-13-06	67.9	145	137	99.1								
104	05-13-06	62.2	103	103	99.4	14.4	0.489	0.148	22.1	0.0000	59	16	224.2
104	12-03-06												
105	05-13-06	47.9	73.9	87.8	73.9								
107	05-15-06	20.8	39.9	40.5	32.9								
112	06-03-06												
113	05-29-06												
115	05-29-06												
116	05-29-06												
117	05-15-06	57.3	90	101	89								
124	05-27-06												
129	05-24-06	42.2	88.8	214	65.1	16	0.542	0.133	38.6	0.0000	144.3	136.8	210.8
133	05-27-06												
135	05-17-06	53.1	80.5	87.8	81.9								
140	05-29-06												
143	05-29-06												

Table 10-1B Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month/ day/year)	Time (hhmm)	Subbasin or source water area	Water temper- ature (°C)	Delta 2H x1000	Delta 18O x1000	Tritium TU	Tritium Plus Minus	CFC11 (pg/kg)	CFC12 (pg/kg)
148	Well 148	06-05-06	1015	Central Kabul	18.1	-55.3	-7.97				
152	Well 152	06-05-06	1000	Central Kabul	16.6	-52.5	-8.24				
153	Well 153	05-20-06	1305	Central Kabul	20	-45.4	-7.34	7.95	0.27	96.3	193
156	Well 156	05-27-06	1000	Central Kabul	15.3	-46.1	-7.18				
157	Well 157	05-27-06	1010	Central Kabul	18	-57.6	-8.56				
162.2	Well 162.2	05-31-06	1020	Central Kabul	16.6	-55.2	-8.58				
163	Well 163	05-31-06	1040	Central Kabul	16.1	-53.3	-8.38				
165	Well 165	05-22-06	1000	Central Kabul	16.2	-59	-9.14	2.81	0.15	160	1630
167	Well 167	06-20-06	0945	Central Kabul	20.4	-62.4	-9.37				
168	Well 168	05-22-06	1040	Central Kabul	18.4	-58	-9.06	7.78	0.28	1560	890
170	Well 170	06-18-06	1150	Central Kabul	17.6	-50.3	-7.75				
172	Well 172	05-22-06	1145	Central Kabul	22.5	-54.6	-8.5	12.3	0.4	222	455
173	Well 173	06-18-06	1050	Central Kabul	16.1	-60.3	-9.17				
180	Spring 180	05-17-06	0945	Central Kabul	18.6	-53.5	-8.6	18.0	0.6	4.91	67.2
181	Chari Sib Spring	05-17-06	1135	Logar	14.8	-55.1	-8.79	12.5	0.4	407	253
182	Well 182	06-02-07	1155	Paghman/Upper Kabul	16	-50.5	-8.48	11.5	0.4	506	246
183	Hootkhel-Nowbahar Pump Station	06-04-07	0905	Central Kabul	18.1	-54.2	-8.62	12.4	0.4	167	8,880
184	Well 184	06-06-07	0920	Paghman/Upper Kabul	15.6	-56.6	-8.96	10.9	0.4	520	1,080
185	Well 185	06-16-07	1050	Central Kabul	20.3	-58.6	-8.97	2.01	0.19	270	161
186	Well 186	06-18-07	0940	Central Kabul	18.5	-62.4	-9.36	0.56	0.10	209	109
187	Hotuk Pump Station	06-20-07	1030	Logar	15.4	-54.6	-8.25	8.5	0.4	265	219
201	Well 201	06-13-06	1045	Logar	14.6	-56.2	-8.41				
202	Well 202	06-13-06	1000	Logar	15.1	-56.8	-8.45				
203	Well 203	05-20-06	1110	Logar	16.2	-56.8	-8.6	12.0	0.4	379	210
204	Well 204	06-13-06	1020	Logar	14.4	-56.4	-8.33				
208	Well 208	05-20-06	0930	Central Kabul	18.3	-56.2	-8.89	12.3	0.4	380	241
210	Well 210	05-31-06	0940	Central Kabul	16.7	-55.1	-8.76				
211	Well 211	06-08-06	0915	Paghman/Upper Kabul	16.1	-56.2	-8.76				
212	Well 212	06-08-06	0950	Paghman/Upper Kabul	15	-55	-8.78				
213	Well 213	05-15-06	1305	Paghman/Upper Kabul	15.1	-54.3	-8.74	14.1	0.4	545	412
214	Well 214	06-11-06	1245	Paghman/Upper Kabul	16.3	-50.6	-8.04				
216	Well 216	06-11-06	1125	Paghman/Upper Kabul	15.4	-53.5	-8.6				
217	Well 217	06-11-06	1100	Paghman/Upper Kabul	17.1	-52.4	-8.43				
218	Well 218	06-20-06	1030	Central Kabul	20.1	-64.5	-9.56				
219	Well 219	06-20-06	1000	Central Kabul	19.1	-63.3	-9.38	2.57	0.17	159	106
220	Well 220	06-20-06	1100	Central Kabul	20.8	-61.9	-9.29				
221	Well 221	12-05-06	1120	Logar	13	-56.1	-8.44	6.77	0.22		
221	Well 221	02-19-07	1120	Logar	13.8			6.80	0.22	224	150
222	Afshar 6B	12-10-06	1220	Paghman/Upper Kabul	12.7	-56.2	-9.04	14.5	0.4		
223	US Embassy CAFE well	02-22-07	1400	Central Kabul	16.3	-59.1	-9.16	6.95	0.25	130	158
301	Istalef River at Istalef	12-04-06	1310	Shomali	5.3	-54.8	-9.44				
301	Istalef River at Istalef	12-18-06	0945	Shomali	4.4	-47.7	-8.38				
301	Istalef River at Istalef	01-02-07	1220	Shomali	4.6	-48.4	-8.42				
301	Istalef River at Istalef	01-16-07	1050	Shomali	4.2	-47.6	-8.49				
301	Istalef River at Istalef	01-30-07	1040	Shomali	7.5	-47.7	-8.39				
301	Istalef River at Istalef	02-13-07	1145	Shomali	7.6	-50.7	-8.75	7.77	0.26	638	326
301	Istalef River at Istalef	02-27-07	1100	Shomali	6.9	-52.3	-8.75				
301	Istalef River at Istalef	03-13-07	1045	Shomali	6	-52	-8.9	10.2	0.4		
301	Istalef River at Istalef	03-27-07	1000	Shomali	11	-52.9	-9.12				
301	Istalef River at Istalef	04-10-07	0845	Shomali	9.4	-51.6	-9.09	10.1	0.4		
301	Istalef River at Istalef	04-24-07	1055	Shomali	12.5	-52.9	-9.16				

Table 10-1B. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	CFC113 pg/kg	Percent Modern CFC11	Percent Modern CFC12	Percent Modern CFC113	N_2 dissolved (mg/L)	Ar dissolved (mg/L)	O_2 dissolved (mg/L)	CO_2 dissolved (mg/L)	CH_4 dissolved (mg/L)	He dissolved cc_STP_g H20x10_9	H_2 dissolved cc_STP_g H20x10_9	Ne dissolved cc_STP_g H20x10_9
148	06-05-06												
152	06-05-06												
153	05-20-06	23.6	19.5	76.3	36.4								
156	05-27-06												
157	05-27-06												
162.2	05-31-06												
163	05-31-06												
165	05-22-06	14.2	32.5	647	21.8	15.7	0.527	0.144	23.5	0.0000	93.2	29.2	236.9
167	06-20-06												
168	05-22-06	36.1	317	352	55.6								
170	06-18-06												
172	05-22-06	25	45	180	38.6								
173	06-18-06												
180	05-17-06	2.43	0.947	25.6	3.55								
181	05-17-06	57.7	78.6	96.2	84.3								
182	06-02-07	60.7	95.9	93	87.3	17.4	0.544	0.138	30	0.0000			
183	06-04-07	27.7	30.7	3260	38.6	18	0.56	0.14	17.9	0.0083			
184	06-06-07	30.3	120	484	54.1	21.1	0.507	0.111	38.1	0.0000			
185	06-16-07	34.4	54.2	64.2	52.8	15.2	0.46	0.125	17.2	0.0000			
186	06-18-07	25.1	51.7	52.2	48.5	18.3	0.485	0.117	7.62	0.0000			
187	06-20-07	50	38.8	65.7	54.3	20	0.615	0.139	32.1	0.0000			
201	06-13-06												
202	06-13-06												
203	05-20-06	49.8	76.8	83	76.7								
204	06-13-06												
208	05-20-06	44	77.2	95.5	67.9								
210	05-31-06												
211	06-08-06												
212	06-08-06												
213	05-15-06	61.2	111	163	94.5								
214	06-11-06												
216	06-11-06												
217	06-11-06												
218	06-20-06												
219	06-20-06	19.8	32.5	42.1	30.6								
220	06-20-06												
221	12-05-06												
221	02-19-07	22.9	44.8	58.5	34.7	15.8	0.538	0.334	22.1	0.0000	1,760	21.9	
222	12-10-06												
223	02-22-07	12.2	26.1	61.8	18.5	16.9	0.548	0.169	23.6	0.0000	695.8	38	
301	12-04-06												
301	12-18-06												
301	01-02-07												
301	01-16-07												
301	01-30-07												
301	02-13-07	89.1	98.4	102	102								
301	02-27-07												
301	03-13-07												
301	03-27-07												
301	04-10-07												
301	04-24-07												

Table 10-1B Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month/ day/year)	Time (hhmm)	Subbasin or source water area	Water temper- ature (°C)	Delta 2H x1000	Delta 18O x1000	Tritium TU	Tritium Plus Minus	CFC11 (pg/kg)	CFC12 (pg/kg)
301	Istalef River at Istalef	06-14-07	0920	Shomali	14.7	-52.4	-9.06			1,090	256
301	Istalef River at Istalef	07-15-07	1105	Shomali	17.8	-48.8	-8.52			398	202
302	Panjshir River at Sayad	12-09-06	1155	Shomali	9.5	-61.9	-10.02				
302	Panjshir River at Sayad	12-26-06	1210	Shomali	11.4	-60.1	-9.79				
302	Panjshir River at Sayad	01-09-07	1115	Shomali	9.1	-61.6	-9.92				
302	Panjshir River at Sayad	01-23-07	1125	Shomali	9.4	-62.4	-9.9				
302	Panjshir River at Sayad	02-06-07	1130	Shomali	12.5	-60.9	-9.81	11.2	0.4	505	250
302	Panjshir River at Sayad	02-20-07	1140	Shomali	10.5	-60.7	-9.84				
302	Panjshir River at Sayad	03-06-07	1100	Shomali	12.7	-59.1	-9.74	10.8	0.4		
302	Panjshir River at Sayad	03-20-07	0945	Shomali	8.9	-63.4	-10.25				
302	Panjshir River at Sayad	04-03-07	1210	Shomali	11.2	-62.1	-9.95	9.9	0.4		
302	Panjshir River at Sayad	04-17-07	0855	Shomali	12.3	-59.7	-9.83				
302	Panjshir River at Sayad	06-19-07	1030	Shomali	14.8	-66.5	-10.68			532	270
303	Barik Ab River	12-26-06	1030	Shomali	2.3	-63.1	-9.91				
303	Barik Ab River	01-09-07	1015	Shomali	0.6	-62.9	-9.73				
303	Barik Ab River	01-23-07	1240	Shomali	0.7	-62.4	-9.7				
303	Barik Ab River	02-20-07	1020	Shomali	11.1	-53.3	-8.51	8.61	0.29	494	270
303	Barik Ab River	03-06-07	1000	Shomali	7.5	-60.2	-9.47				
303	Barik Ab River	03-20-07	0830	Shomali	9.4	-50.5	-8.52	8.67	0.29		
303	Barik Ab River	04-03-07	1055	Shomali	9.2	-51.3	-8.84				
303	Barik Ab River	04-17-07	1000	Shomali	14.8	-55.4	-9.48	6.65	0.24		
321	Logar River	12-05-06	1010	Logar	4.9	-61	-9.44				
321	Logar River	12-19-06	1040	Logar	4.1	-61.6	-9.28				
321	Logar River	01-06-07	0950	Logar	0.5	-61.1	-9.28				
321	Logar River	01-21-07	1050	Logar	0.7	-61.5	-9.24				
321	Logar River	02-07-07	1100	Logar	7.8	-61.2	-9.41	6.52	0.23	623	333
321	Logar River	02-21-07	1055	Logar	6.2	-60.4	-9.25				
321	Logar River	03-07-07	1000	Logar	9.1	-60.2	-9.02	6.7	0.4		
321	Logar River	03-19-07	0955	Logar	9.6	-58.6	-9.14				
321	Logar River	04-04-07	0955	Logar	11.2	-60.2	-9.22	8.0	0.4		
321	Logar River	04-18-07	1010	Logar	16.4	-59.5	-9.27				
321	Logar River	06-20-07	1110	Logar	22.2	-51.7	-7.65			238	162
322	Kabul River at Tang-i-gharu	12-05-06	1320	Central Kabul	6.2	-58	-8.95				
322	Kabul River at Tang-i-gharu	12-25-06	1335	Central Kabul		-60	-9.23				
322	Kabul River at Tang-i-gharu	01-06-07	1225	Central Kabul	0.8	-59.9	-9.12				
322	Kabul River at Tang-i-gharu	01-21-07	1340	Central Kabul	4.2	-58.4	-9.04				
322	Kabul River at Tang-i-gharu	02-07-07	1300	Central Kabul	10	-59.6	-9.11	7.15	0.25	701	319
322	Kabul River at Tang-i-gharu	02-21-07	1340	Central Kabul	7.8	-60.7	-9.24				
322	Kabul River at Tang-i-gharu	03-07-07	1000	Central Kabul	10.9	-57.7	-8.93	8.1	0.4		
322	Kabul River at Tang-i-gharu	03-19-07	1105	Central Kabul	8.8	-55	-8.8				
322	Kabul River at Tang-i-gharu	04-04-07	1200	Central Kabul	11.8			9.2	0.4		
322	Kabul River at Tang-i-gharu	04-18-07	1235	Central Kabul	16.9	-59.3	-9.48				
322	Kabul River at Tang-i-gharu	06-04-07	1115	Central Kabul	22.6	-47.7	-7.71			78.9	178
322	Kabul River at Tang-i-gharu	07-04-07	0955	Central Kabul	22.9	-54.1	-8.27			363	166
323	Paghman River at Paghman	12-10-06	1300	Paghman/Upper Kabul	8.5	-47.2	-8.62				
323	Paghman River at Paghman	12-25-06	1205	Paghman/Upper Kabul	3.7	-49.8	-8.7				
323	Paghman River at Paghman	01-10-07	1220	Paghman/Upper Kabul	4.6	-49.2	-8.58				
323	Paghman River at Paghman	01-25-07	1130	Paghman/Upper Kabul	7.5	-48	-8.6				
323	Paghman River at Paghman	02-10-07	1350	Paghman/Upper Kabul	5.7	-52.9	-9.22	7.15	0.25	689	331
323	Paghman River at Paghman	02-24-07	1245	Paghman/Upper Kabul	6.3	-52.9	-9.04				
323	Paghman River at Paghman	03-10-07	1225	Paghman/Upper Kabul	7.7	-55.1	-9.31	10.2	0.4		
323	Paghman River at Paghman	03-24-07	1215	Paghman/Upper Kabul	12.3	-56.4	-9.4				

Table 10-1B. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	CFC113 pg/kg	Percent Modern CFC11	Percent Modern CFC12	Percent Modern CFC113	N_2 dissolved (mg/L)	Ar dissolved (mg/L)	O_2 dissolved (mg/L)	CO_2 dissolved (mg/L)	CH4 dissolved (mg/L)	He dissolved cc_STP_g H20x10_9	H_2 dissolved cc_STP_g H20x10_9	Ne dissolved cc_STP_g H20x10_9
301	06-14-07	72.2	245	114	126								
301	07-15-07	51	104	103	106								
302	12-09-06												
302	12-26-06												
302	01-09-07												
302	01-23-07												
302	02-06-07	64	92.4	90.8	89								
302	02-20-07												
302	03-06-07												
302	03-20-07												
302	04-03-07												
302	04-17-07												
302	06-19-07	71.3	114	115	119								
303	12-26-06												
303	01-09-07												
303	01-23-07												
303	02-20-07	67	88.6	96.1	91								
303	03-06-07												
303	03-20-07												
303	04-03-07												
303	04-17-07												
321	12-05-06	84.5	92.4	100	93.1								
321	12-19-06												
321	01-06-07												
321	01-21-07												
321	02-07-07												
321	02-21-07												
321	03-07-07	32.4	76.4	99	83.9								
321	03-19-07												
321	04-04-07												
321	04-18-07												
321	06-20-07												
322	12-05-06												
322	12-25-06												
322	01-06-07												
322	01-21-07												
322	02-07-07	82	116	106	101								
322	02-21-07												
322	03-07-07												
322	03-19-07												
322	04-04-07												
322	04-18-07												
322	06-04-07	40	0	110	105								
322	07-04-07	39.1	120	103	104								
323	12-10-06												
323	12-25-06												
323	01-10-07												
323	01-25-07												
323	02-10-07	92.6	100	99	99.4								
323	02-24-07												
323	03-10-07												
323	03-24-07												

Table 10-1B Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Local name	Date (month/ day/year)	Time (hhmm)	Sub basin or source water area	Water temper-ature (°C)	Delta 2H x1000	Delta 18O x1000	Tritium TU	Tritium Plus Minus	CFC11 (pg/kg)	CFC12 (pg/kg)
323	Paghman River at Paghman	04-07-07	1230	Paghman/Upper Kabul	11.8	-55.6	-9.44	9.6	0.4		
323	Paghman River at Paghman	06-02-07	1030	Paghman/Upper Kabul	18	-57.2	-9.58			399	208
323	Paghman River at Paghman	07-02-07	1005	Paghman/Upper Kabul	18	-55.6	-9.38			4.46	51.9
324	Kabul River at Tangi Saedan	12-10-06	1020	Paghman/Upper Kabul	5.5	-54.8	-8.92				
324	Kabul River at Tangi Saedan	12-25-06	1045	Paghman/Upper Kabul	14.7	-56.9	-9.2				
324	Kabul River at Tangi Saedan	01-10-07	0955	Paghman/Upper Kabul	2.7	-55.2	-8.96				
324	Kabul River at Tangi Saedan	01-25-07	1010	Paghman/Upper Kabul	6.3	-54.3	-8.98				
324	Kabul River at Tangi Saedan	02-10-07	1100	Paghman/Upper Kabul	6.9	-58.8	-9.3	10.8	0.3	656	327
324	Kabul River at Tangi Saedan	02-24-07	1130	Paghman/Upper Kabul	6.3	-54.5	-9.01				
324	Kabul River at Tangi Saedan	03-10-07	0900	Paghman/Upper Kabul	6.4	-57.4	-9.21	10.6	0.3		
324	Kabul River at Tangi Saedan	03-24-07	1040	Paghman/Upper Kabul	8.1	-59.3	-9.47				
324	Kabul River at Tangi Saedan	04-07-07	1010	Paghman/Upper Kabul	11.2	-58.8	-9.55	10.8	0.5		
324	Kabul River at Tangi Saedan	04-21-07	1015	Paghman/Upper Kabul	11.4	-59.3	-9.64				
987	Panjshir River at Shukhi	05-11-06	0000	Panjsher		-61.8	-10.13	12.1	0.6		

Table 10-1B. Water-quality data for the period July 2004 through July 2007, for the Kabul Basin, Afghanistan.—Continued

ID	Date (month/ day/year)	CFC113 pg/kg	Percent Modern CFC11	Percent Modern CFC12	Percent Modern CFC113	N_2 dissolved (mg/L)	Ar dissolved (mg/L)	O_2 dissolved (mg/L)	CO_2 dissolved (mg/L)	CH4 dissolved (mg/L)	He dissolved cc_STP_g H20x10_9	H_2 dissolved cc_STP_g H20x10_9	Ne dissolved cc_STP_g H20x10_9
323	04-07-07												
323	06-02-07	52.3	100	103	103								
323	07-02-07	1.59	1.25	28.2	3.53								
324	12-10-06												
324	12-25-06												
324	01-10-07												
324	01-25-07												
324	02-10-07	90.2	95.7	97.3	97.4								
324	02-24-07												
324	03-10-07												
324	03-24-07												
324	04-07-07												
324	04-21-07												
987	05-11-06												

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Appendix 11. Isotopic Data Results

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Appendix 11. Isotopic Data Results

In this study, 80 groundwater, 4 karez, 7 spring, and 76 surface-water samples were collected and analyzed for determination of δ^2H and δ^{18}O. Between early December 2006 and mid July 2007, surface-water samples were collected at seven sites. The analytical results are shown in table 11-1. Stable hydrogen and oxygen isotopic compositions of these surface waters as a function of time are shown in figures 11-1 and 11-2.

Surface Waters

The measurement data in figures 11-1 and 11-2 show a number of features. Samples from the Istalef River at Istalef and the Paghman River at Paghman surface-water sites are most enriched in ^{2}H and ^{18}O in accord with the relatively low-elevation source areas in the foothills west of the Kabul Basin. Samples from the Logar River site and Kabul River sites have intermediate δ^2H and δ^{18}O values reflecting a higher-elevation source area. Between mid-April and June, the δ^2H and δ^{18}O values of the Logar and Kabul River water increased dramatically, presumably reflecting the sharply decreasing contribution of snowmelt water. The δ^2H and δ^{18}O values of samples from the Barik Ab River near Bagram were highly variable and may reflect a relatively flashy surface-water system. The lowest δ^2H and δ^{18}O values were those from the Panjsher River at Sayad and reflect snowmelt water from the high-elevation source area stretching to the Khyber Pass in Pakistan. The lowest δ^2H and δ^{18}O values in late June presumably reflect the highest fraction of high-elevation snowmelt water.

Definition of the Deuterium Excess

The relation between δ^2H and δ^{18}O in all water samples analyzed in this study is shown in figure 23. The Global Meteoric Water Line (GMWL) shown is a least squares regression of δ^2H and δ^{18}O of precipitation at over 200 globally distributed stations (Rozanski and others, 1993) and follows the relation

$$\delta^2\mathrm{H} = 8.20\delta^{18}\mathrm{O} + 11.27 \times 10^3 \qquad (11\text{-}1)$$

The values of 10^3 are needed to express this relation as a quantity equation rather than as a numeric value equation, which is desired in the International System of Units (SI). The deuterium excess, *d*, was defined by Dansgaard (1964) as

$$d = \delta^2\mathrm{H} - 8\,\delta^{18}\mathrm{O} \qquad (11\text{-}2)$$

The value of *d* is a function of relative humidity (Clark and Fritz, 1997; Merlivat and Jouzel, 1979) with a $10^3\,d$ value +20 indicating 70 percent relative humidity and a value of +10 indicating 85 percent relative humidity, which is the global mean. Values of *d* are shown in table 11-1.

On the basis of *d* values and δ^2H and δ^{18}O values (tables 11-1 and 11-2), there appears to be four distinguishable surface-water sources. Samples from the Istalef River at Istalef and the Paghman River at Paghman have overlapping *d* values and reflect precipitation in the most arid environment (relative humidity is about 70 percent). Samples from the Kabul River at Tang-i-Saidan and the Barik Ab River near Bagram have $10^3\,d$ values of about +16.8 and form the second distinguishable source. Samples from the Kabul River at Tang-i-Gharu and the Logar River indicate a third distinguishable source with $10^3\,d$ values of about 13.5. The fourth distinguishable source is the Panjsher River at Sayad, which is distinguishable because of its low δ^2H and δ^{18}O values discussed above. The Barik Ab River near Bagram shows substantial variability in its *d* value and in its δ^2H and δ^{18}O values (tables 11-1 and 11-2, figs. 11-1 and 11-2) and may be a small and flashy surface-water source.

There is little evidence of evaporation affecting the isotopic composition of surface waters, which is surprising in this arid environment. The slope of evaporating water on a δ^2H versus δ^{18}O plot typically is substantially less than 8, and evaporated waters typically plot to the right of the GMWL.

The International Atomic Energy Agency (IAEA) reports δ^2H and δ^{18}O values for monthly integrated samples of precipitation collected between January 1962 and September 1989 in Kabul (International Atomic Energy Agency/WMO, 2004). The $10^3\,\delta^2$H values range from -103 to +33 and the $10^3\,\delta^{18}$O values range from –15.98 to +3.07, and the samples with $10^3\,\delta^2$H values greater than +15 show substantial evaporation on a δ^2H versus δ^{18}O plot and were not included in calculations herein. The linear least squares regression of samples having $10^3\,\delta^2$H values less than +15 is described by

$$10^3\,\delta^2\mathrm{H} = 7.73 \times 10^3\,\delta^{18}\mathrm{O} + 16.14 \qquad (11\text{-}3)$$

and is shown in figure 23. This precipitation line is in good agreement with samples from the Istalef River at Istalef and the Paghman River at Paghman.

Table 11-1. Stable hydrogen and oxygen isotopic compositions of water analyzed in this study.

[GW, groundwater; KZ, karez; SP, spring; SW, surface water; VSMOW, Vienna Standard Mean Ocean Water; d, deuterium excess]

Site identification number	Site type	Date	Groundwater area Surface-water site	10^3 δ^2H relative to VSMOW	10^3 δ^{18}O relative to VSMOW	10^3 *d*
64	GW	06-24-2006	Central Kabul	-55.9	-8.87	15.06
65	GW	05-25-2006	Central Kabul	-60.7	-9.28	13.54
124	GW	05-27-2006	Central Kabul	-56.1	-8.87	14.86
129	GW	05-24-2006	Central Kabul	-55.6	-8.79	14.72
133	GW	05-27-2006	Central Kabul	-55.0	-8.52	13.16
148	GW	06-05-2006	Central Kabul	-55.3	-7.97	8.46
152	GW	06-05-2006	Central Kabul	-52.5	-8.24	13.42
153	GW	05-20-2006	Central Kabul	-45.4	-7.34	13.32
156	GW	05-27-2006	Central Kabul	-46.1	-7.18	11.34
157	GW	05-27-2006	Central Kabul	-57.6	-8.56	10.88
162.2	GW	05-31-2006	Central Kabul	-55.2	-8.58	13.44
163	GW	05-31-2006	Central Kabul	-53.3	-8.38	13.74
165	GW	05-22-2006	Central Kabul	-59.0	-9.14	14.12
167	GW	06-20-2006	Central Kabul	-62.4	-9.37	12.56
168	GW	05-22-2006	Central Kabul	-58.0	-9.06	14.48
170	GW	06-18-2006	Central Kabul	-50.3	-7.75	11.7
172	GW	05-22-2006	Central Kabul	-54.6	-8.50	13.4
173	GW	06-18-2006	Central Kabul	-60.3	-9.17	13.06
183	GW	06-04-2007	Central Kabul	-54.2	-8.62	14.76
185	GW	06-16-2007	Central Kabul	-58.6	-8.97	13.16
186	GW	06-18-2007	Central Kabul	-62.4	-9.36	12.48
208	GW	05-20-2006	Central Kabul	-56.2	-8.89	14.92
210	GW	05-31-2006	Central Kabul	-55.1	-8.76	14.98
218	GW	06-20-2006	Central Kabul	-64.5	-9.56	11.98
219	GW	06-20-2006	Central Kabul	-63.3	-9.38	11.74
220	GW	06-20-2006	Central Kabul	-61.9	-9.29	12.42
223	GW	02-22-2007	Central Kabul	-59.1	-9.16	14.18
8	GW	06-07-2006	Deh Sabz	-55.0	-8.29	11.32
13	GW	05-16-2006	Deh Sabz	-56.6	-8.98	15.24
15	GW	05-30-2006	Deh Sabz	-52.4	-8.02	11.76
37	GW	05-14-2006	Deh Sabz	-63.0	-9.69	14.52
54	GW	05-21-2006	Deh Sabz	-59.1	-9.03	13.14
2.1	GW	06-07-2006	Eastern Front	-58.9	-9.70	18.7
7	GW	06-04-2006	Eastern Front	-48.8	-8.78	21.44
59.1	GW	05-10-2006	Eastern Front	-55.2	-9.30	19.2
71	GW	06-05-2007	Eastern Front	-56.5	-9.46	19.18
116	GW	05-29-2006	Logar	-54.7	-8.58	13.94
135	GW	05-17-2006	Logar	-53.9	-8.28	12.34

Table 11-1. Stable hydrogen and oxygen isotopic compositions of water analyzed in this study.—Continued

[GW, groundwater; KZ, karez; SP, spring; SW, surface water; VSMOW, Vienna Standard Mean Ocean Water; d, deuterium excess]

Site identification number	Site type	Date	Groundwater area Surface-water site	10^3 δ^2H relative to VSMOW	10^3 δ^{18}O relative to VSMOW	10^3 *d*
140	GW	05-29-2006	Logar	-54.7	-8.18	10.74
143	GW	05-29-2006	Logar	-55.3	-8.27	10.86
187	GW	06-20-2007	Logar	-54.6	-8.25	11.4
201	GW	06-13-2006	Logar	-56.2	-8.41	11.08
202	GW	06-13-2006	Logar	-56.8	-8.45	10.8
203	GW	05-20-2006	Logar	-56.8	-8.60	12
204	GW	06-13-2006	Logar	-56.4	-8.33	10.24
221	GW	12-05-2006	Logar	-56.1	-8.44	11.42
107	GW	05-15-2006	Paghman and Upper Kabul	-59.8	-9.29	14.52
112	GW	06-03-2006	Paghman and Upper Kabul	-55.3	-8.47	12.46
113	GW	05-29-2006	Paghman and Upper Kabul	-56.2	-8.84	14.52
115	GW	05-29-2006	Paghman and Upper Kabul	-47.5	-8.43	19.94
117	GW	05-15-2006	Paghman and Upper Kabul	-53.1	-8.48	14.74
182	GW	06-02-2007	Paghman and Upper Kabul	-50.5	-8.48	17.34
184	GW	06-06-2007	Paghman and Upper Kabul	-56.6	-8.96	15.08
211	GW	06-08-2006	Paghman and Upper Kabul	-56.2	-8.76	13.88
212	GW	06-08-2006	Paghman and Upper Kabul	-55.0	-8.78	15.24
213	GW	05-15-2006	Paghman and Upper Kabul	-54.3	-8.74	15.62
214	GW	06-11-2006	Paghman and Upper Kabul	-50.6	-8.04	13.72
216	GW	06-11-2006	Paghman and Upper Kabul	-53.5	-8.60	15.3
217	GW	06-11-2006	Paghman and Upper Kabul	-52.4	-8.43	15.04
222	GW	12-10-2006	Paghman and Upper Kabul	-56.2	-9.04	16.12
22.1	GW	06-12-2006	Shomali	-47.9	-8.11	16.98
24	GW	06-14-2006	Shomali	-50.1	-8.47	17.66
25	GW	06-14-2006	Shomali	-52.8	-8.55	15.6
28	GW	05-23-2006	Shomali	-52.4	-8.49	15.52
42	GW	05-28-2006	Shomali	-55.8	-9.08	16.84
47	GW	05-30-2006	Shomali	-53.7	-8.62	15.26
72	GW	06-12-2007	Shomali	-50.0	-8.39	17.12
74	GW	06-19-2007	Shomali	-57.5	-9.17	15.86
20	GW	06-10-2006	Western Front	-45.8	-8.16	19.48
21	GW	06-12-2006	Western Front	-53.1	-9.01	18.98
33	GW	05-23-2006	Western Front	-49.5	-8.43	17.94
41	GW	05-28-2006	Western Front	-50.2	-8.70	19.4
43	GW	05-28-2006	Western Front	-52.3	-8.90	18.9
45	GW	05-30-2006	Western Front	-56.2	-9.29	18.12
52	GW	06-10-2006	Western Front	-45.7	-8.15	19.5

Table 11-1. Stable hydrogen and oxygen isotopic compositions of water analyzed in this study.—Continued

[GW, groundwater; KZ, karez; SP, spring; SW, surface water; VSMOW, Vienna Standard Mean Ocean Water; d, deuterium excess]

Site identification number	Site type	Date	Groundwater area Surface-water site	10^3 δ^2H relative to VSMOW	10^3 $\delta^{18}O$ relative to VSMOW	10^3 *d*
67	GW	12-09-2006	Western Front	-56.9	-9.34	17.82
100	GW	06-03-2006	Western Front	-46.8	-8.19	18.72
104	GW	05-13-2006	Paghman and Upper Kabul	-50.3	-8.46	17.38
104	GW	12-03-2006	Paghman and Upper Kabul	-48.3	-8.34	18.42
73	GW	06-17-2007	Western Front	-55.0	-9.18	18.44
6	KZ	05-10-2006	Eastern Front	-54.0	-9.04	18.32
10	KZ	05-10-2006	Eastern Front	-54.6	-9.23	19.24
69.1	KZ	05-10-2006	Eastern Front	-50.0	-8.72	19.76
105	KZ	05-13-2006	Paghman and Upper Kabul	-41.9	-6.94	13.62
180	SP	05-17-2006	Central Kabul	-53.5	-8.60	15.3
66.1	SP	05-10-2006	Eastern Front	-50.5	-8.85	20.3
181	SP	05-17-2006	Logar	-55.1	-8.79	15.22
67.1	SP	05-23-2006	Shomali	-49.9	-8.24	16.02
68.1	SP	05-21-2006	Shomali	-50.1	-8.38	16.94
101	SP	05-13-2006	Western Front	-45.9	-8.16	19.38
67.2	SP	06-17-2006	Western Front	-51.7	-8.53	16.54
301	SW	12-04-2006	Istalef River	-54.8	-9.44	20.72
301	SW	12-18-2006	Istalef River	-47.7	-8.38	19.34
301	SW	01-02-2007	Istalef River	-48.4	-8.42	18.96
301	SW	01-16-2007	Istalef River	-47.6	-8.49	20.32
301	SW	01-30-2007	Istalef River	-47.7	-8.39	19.42
301	SW	02-13-2007	Istalef River	-50.7	-8.75	19.3
301	SW	02-27-2007	Istalef River	-52.3	-8.75	17.7
301	SW	03-13-2007	Istalef River	-52.0	-8.90	19.2
301	SW	03-27-2007	Istalef River	-52.9	-9.12	20.06
301	SW	04-10-2007	Istalef River	-51.6	-9.09	21.12
301	SW	04-24-2007	Istalef River	-52.9	-9.16	20.38
301	SW	06-14-2007	Istalef River	-52.4	-9.06	20.08
301	SW	07-15-2007	Istalef River	-48.8	-8.52	19.36
302	SW	12-09-2006	Panjsher River at Sayad	-61.9	-10.02	18.26

Table 11-1. Stable hydrogen and oxygen isotopic compositions of water analyzed in this study.—Continued

[GW, groundwater; KZ, karez; SP, spring; SW, surface water; VSMOW, Vienna Standard Mean Ocean Water; d, deuterium excess]

Site identification number	Site type	Date	Groundwater area Surface-water site	10^3 δ^2H relative to VSMOW	10^3 $\delta^{18}O$ relative to VSMOW	10^3 d
302	SW	12-26-2006	Panjsher River at Sayad	-60.1	-9.79	18.22
302	SW	01-09-2007	Panjsher River at Sayad	-61.6	-9.92	17.76
302	SW	01-23-2007	Panjsher River at Sayad	-62.4	-9.90	16.8
302	SW	02-06-2007	Panjsher River at Sayad	-60.9	-9.81	17.58
302	SW	02-20-2007	Panjsher River at Sayad	-60.7	-9.84	18.02
302	SW	03-06-2007	Panjsher River at Sayad	-59.1	-9.74	18.82
302	SW	03-20-2007	Panjsher River at Sayad	-63.4	-10.25	18.6
302	SW	04-03-2007	Panjsher River at Sayad	-62.1	-9.95	17.5
302	SW	04-17-2007	Panjsher River at Sayad	-59.7	-9.83	18.94
302	SW	06-19-2007	Panjsher River at Sayad	-66.5	-10.68	18.94
303	SW	12-26-2006	Barik Ab River	-63.1	-9.91	16.18
303	SW	01-09-2007	Barik Ab River	-62.9	-9.73	14.94
303	SW	01-23-2007	Barik Ab River	-62.4	-9.70	15.2
303	SW	02-20-2007	Barik Ab River	-53.3	-8.51	14.78
303	SW	03-06-2007	Barik Ab River	-60.2	-9.47	15.56
303	SW	03-20-2007	Barik Ab River	-50.5	-8.52	17.66
303	SW	04-03-2007	Barik Ab River	-51.3	-8.84	19.42
303	SW	04-17-2007	Barik Ab River	-55.4	-9.48	20.44
321	SW	12-05-2006	Logar River	-61.0	-9.44	14.52
321	SW	12-19-2006	Logar River	-61.6	-9.28	12.64
321	SW	01-06-2007	Logar River	-61.1	-9.28	13.14
321	SW	01-21-2007	Logar River	-61.5	-9.24	12.42
321	SW	02-07-2007	Logar River	-61.2	-9.41	14.08
321	SW	02-21-2007	Logar River	-60.4	-9.25	13.6
321	SW	03-07-2007	Logar River	-60.2	-9.02	11.96
321	SW	03-19-2007	Logar River	-58.6	-9.14	14.52
321	SW	04-04-2007	Logar River	-60.2	-9.22	13.56
321	SW	04-18-2007	Logar River	-59.5	-9.27	14.66
321	SW	06-20-2007	Logar River	-51.7	-7.65	9.5
322	SW	12-05-2006	Kabul River at Tang-i-Gharu	-58.0	-8.95	13.6
322	SW	12-25-2006	Kabul River at Tang-i-Gharu	-60.0	-9.23	13.84
322	SW	01-06-2007	Kabul River at Tang-i-Gharu	-59.9	-9.12	13.06
322	SW	01-21-2007	Kabul River at Tang-i-Gharu	-58.4	-9.04	13.92
322	SW	02-07-2007	Kabul River at Tang-i-Gharu	-59.6	-9.11	13.28
322	SW	02-21-2007	Kabul River at Tang-i-Gharu	-60.7	-9.24	13.22
322	SW	03-07-2007	Kabul River at Tang-i-Gharu	-57.7	-8.93	13.74
322	SW	03-19-2007	Kabul River at Tang-i-Gharu	-55.0	-8.80	15.4

Table 11-1. Stable hydrogen and oxygen isotopic compositions of water analyzed in this study.—Continued

[GW, groundwater; KZ, karez; SP, spring; SW, surface water; VSMOW, Vienna Standard Mean Ocean Water; d, deuterium excess]

Site identification number	Site type	Date	Groundwater area Surface-water site	10^3 δ^2H relative to VSMOW	10^3 $\delta^{18}O$ relative to VSMOW	10^3 *d*
322	SW	04-18-2007	Kabul River at Tang-i-Gharu	-59.3	-9.48	16.54
322	SW	06-04-2007	Kabul River at Tang-i-Gharu	-47.7	-7.71	13.98
322	SW	07-04-2007	Kabul River at Tang-i-Gharu	-54.1	-8.27	12.06
323	SW	12-10-2006	Paghman River at Pul-i-Sokhta	-47.2	-8.62	21.76
323	SW	12-25-2006	Paghman River at Pul-i-Sokhta	-49.8	-8.70	19.8
323	SW	01-10-2007	Paghman River at Pul-i-Sokhta	-49.2	-8.58	19.44
323	SW	01-25-2007	Paghman River at Pul-i-Sokhta	-48.0	-8.60	20.8
323	SW	02-10-2007	Paghman River at Pul-i-Sokhta	-52.9	-9.22	20.86
323	SW	02-24-2007	Paghman River at Pul-i-Sokhta	-52.9	-9.04	19.42
323	SW	03-10-2007	Paghman River at Pul-i-Sokhta	-55.1	-9.31	19.38
323	SW	03-24-2007	Paghman River at Pul-i-Sokhta	-56.4	-9.40	18.8
323	SW	04-07-2007	Paghman River at Pul-i-Sokhta	-55.6	-9.44	19.92
323	SW	06-02-2007	Paghman River at Pul-i-Sokhta	-57.2	-9.58	19.44
323	SW	07-02-2007	Paghman River at Pul-i-Sokhta	-55.6	-9.38	19.44
324	SW	12-10-2006	Kabul River at Tangi Saidan	-54.8	-8.92	16.56
324	SW	12-25-2006	Kabul River at Tangi Saidan	-56.9	-9.20	16.7
324	SW	01-10-2007	Kabul River at Tangi Saidan	-55.2	-8.96	16.48
324	SW	01-25-2007	Kabul River at Tangi Saidan	-54.3	-8.98	17.54
324	SW	02-10-2007	Kabul River at Tangi Saidan	-58.8	-9.30	15.6
324	SW	02-24-2007	Kabul River at Tangi Saidan	-54.5	-9.01	17.58
324	SW	03-10-2007	Kabul River at Tangi Saidan	-57.4	-9.21	16.28
324	SW	03-24-2007	Kabul River at Tangi Saidan	-59.3	-9.47	16.46
324	SW	04-07-2007	Kabul River at Tangi Saidan	-58.8	-9.55	17.6
324	SW	04-21-2007	Kabul River at Tangi Saidan	-59.3	-9.64	17.82
987	SW	05-11-2006	Panjshir River at Shukhi	-61.8	-10.13	19.24

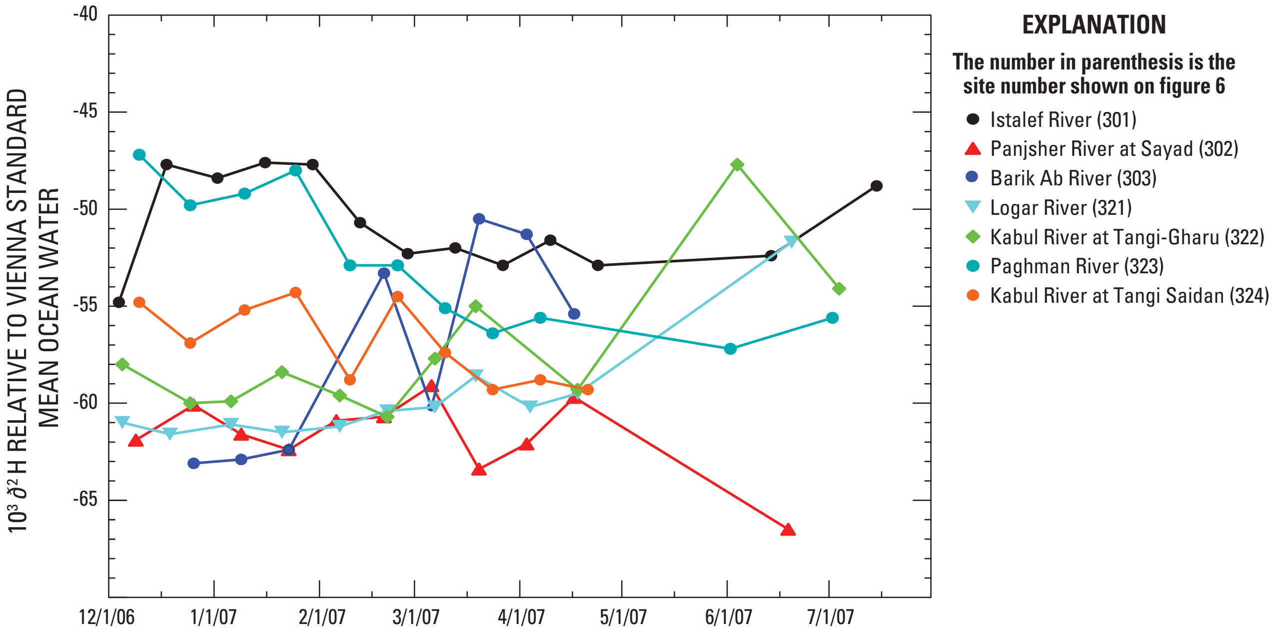

Figure 11-1. Hydrogen isotopic composition, relative to Vienna Standard Mean Ocean Water (VSMOW), of surface water over time in the Kabul Basin, Afghanistan.

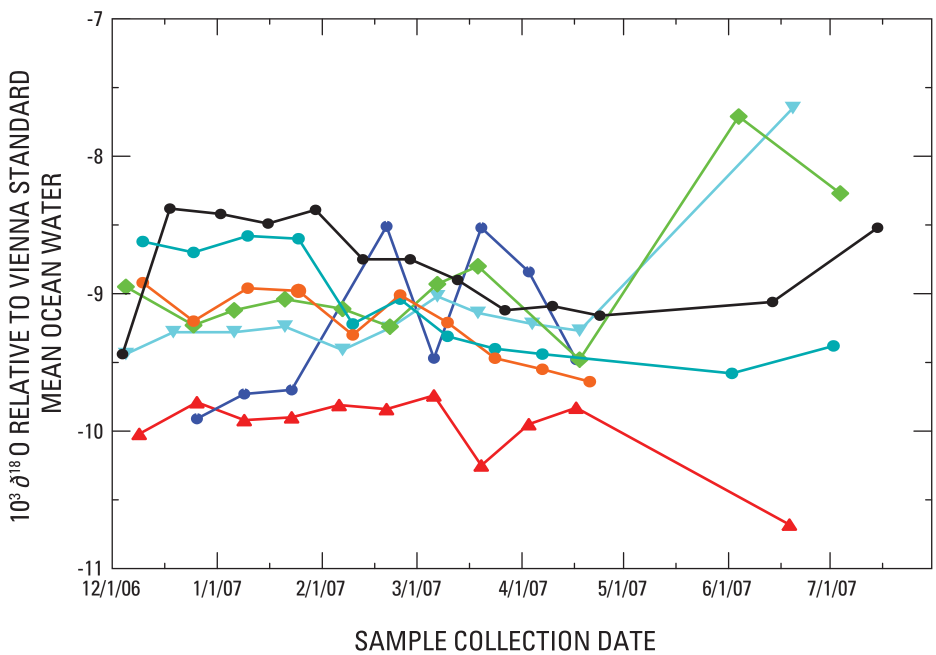

Figure 11-2. Oxygen isotopic composition, relative to Vienna Standard Mean Ocean Water (VSMOW), of surface water over time in the Kabul Basin, Afghanistan.

Table 11-2. Mean deuterium excess, *d*, of selected surface waters.

Station	Site number	10^3 *d* Mean	1-σ standard deviation
Paghman River at Pul-i-Sokhta	323	19.91	0.87
Istalef River	301	19.69	0.89
Panjsher River at Sayad	302	18.13	0.68
Kabul River at Tangi Saidan	324	16.86	0.73
Barik Ab River	303	16.77	2.17
Kabul River at Tangi-Gharu	322	13.88	1.19
Logar River at Sang-i-Naweshta	321	13.15	1.51

Groundwater Source Areas

Groundwaters, karezes, and springs are plotted on figure 23, and with few exceptions, they plot near one of the four distinguishable surface-water sources discussed above. Samples from groundwaters, karezes, and springs were separated into seven distinguishable groundwater source areas: Western Front Source Area, Shomali subbasin, Deh Sabz subbasin, Eastern Front Source Area, Paghman and Upper Kabul subbasin, Central Kabul subbasin, and Logar subbasin (table 11-1, fig. 1). Results are plotted and discussed by groundwater source area below.

Western Front

The groundwater and spring sites in the Western Front Source Area are comprised of wells 20, 21, 33, 41, 43, 45, 52, 67, 100 (Swedish well 224), and 104 and spring 101 (fig. 6). Water from these sites is expected to be runoff water, such as rain and snowmelt water from the Paghman Mountains. Examples of such surface water that presumably infiltrates along the western basin flanks are the Istalef River and the Paghman River. In figure 11-3, many of the groundwater samples and one of the spring-water samples lie below the lines for the Istalef River at Istalef and the Paghman River at Paghman samples—their 10^3 *d* values range between 16.5 and 18, in accord with groundwater recharge during periods with slightly higher relative humidity than the 70 percent mentioned above. Wells 41, 43, and 45 are along the Istalef River and their δ^2H and $\delta^{18}O$ values are in accord with groundwater recharge from this river.

The chloride mass concentrations of samples from the Istalef River at Istalef and the Paghman River at Paghman were in the range of 1 or 2 mg/L at high stage when most groundwater recharge is expected. The chloride mass concentration in Western Front Source Area groundwater ranged from 3 to 18 mg/L with an exceptional value for well 104 of 65 mg/L. If chloride were concentrated in well 104 by evaporation, one would expect to observe a strong enrichment in ^2H and ^{18}O. However, figure 11-3 shows no substantial enrichment in these isotopes, ruling out evaporative enrichment as a mechanism to explain this high chloride concentration.

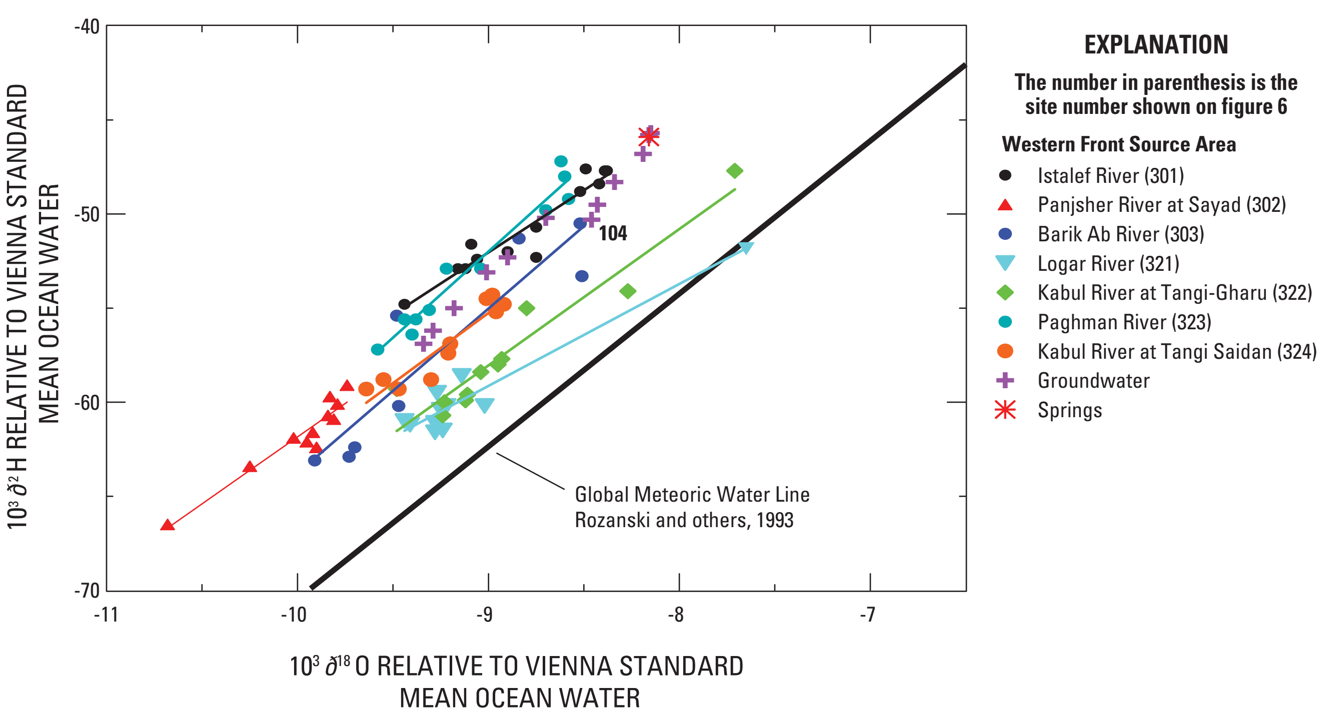

Figure 11-3. The relation between hydrogen and oxygen isotopic composition, relative to Vienna Standard Mean Ocean Water (VSMOW), of all surface waters and of groundwaters and springs in the Western Front Source Area.

Shomali Subbasin

The groundwater and spring sites in the Shomali subbasin are comprised of wells 22.1, 24, 25, 28, 42, 47, 72, and 74 and springs 67A, 67.1 (Kheelre spring), and 68 (fig. 6). Samples from these sites have $10^3\ d$ values ranging from 15.3 to 17.7. Although springs 67.2 and 67.1 lie near the Istalef River (figs. 1 and 6), their $10^3\ d$ values of 16.54 and 16.02 (fig. 11-1) indicate they were not recharged from modern Istalef River water, which has a $10^3\ d$ value of 19.69 ± 0.89, but from a precipitation source with a relative humidity greater than that which serves as the source area of the Istalef River (fig. 11-4). The same comparison holds for spring 68 and near-by well 52. Well 52 is relatively shallow (23.1 m) and is a good example of a Western Front Source Area with its $10^3\ d$ value of 19.5. Spring 68.1, however, reflects a source area with precipitation having higher relative humidity ($10^3\ d$ is 16.02) than that for the Western Front Source Area.

The chloride mass concentration in Shomali subbasin ranged from 4 to 18 mg/L with two exceptional values for wells 47 and 74 of 139 and 119 mg/L, respectively. If chloride were concentrated in wells 47 or 74 by evaporation, one would expect to observe a strong enrichment in ^2H and ^{18}O, but figure 11-4 shows no substantial enrichment in these isotopes, ruling out evaporative enrichment as a mechanism to explain these high chloride concentrations.

Deh Sabz Subbasin

The groundwater sites in the Deh Sabz subbasin are comprised of wells 8, 13, 15, 37, and 54 (figs. 1 and 6), and samples from these sites have $10^3\ d$ values ranging from 11.3 to 15.2. In figure 11-5, these groundwaters plot closest to the Kabul River at Tang-i-Gharu and Logar River surface-water samples. Some groundwater may flow from the Central Kabul subbasin, through narrow gaps in the interbasin ridge, to the Deh Sabz subbasin.

The chloride mass concentrations of samples from the Kabul River at Tang-i-Gharu and Logar River were in the range of 11 to 19 mg/L at high stage when most groundwater recharge is expected. The chloride mass concentrations of samples from the Deh Sabz subbasin ranged from 29 to 68 mg/L with two exceptional values for wells 8 and 15 of 240 and 315 mg/L, respectively. If chloride were concentrated in wells 8 and 15 by evaporation, one would expect to observe a strong enrichment in ^2H and ^{18}O. Wells 8 and 15 have the highest δ^2H and $\delta^{18}O$ values of the Deh Sabz subbasin (fig. 11-5); thus, enrichment of chloride may be due in part to evaporative enrichment. However, the magnitudes of the enrichment in $10^3\ \delta^{18}O$ are relatively small (approximately 1), which would increase chloride concentration by less than a factor of two. Therefore, other mechanisms are needed to explain the high chloride concentrations in well 8 and 15.

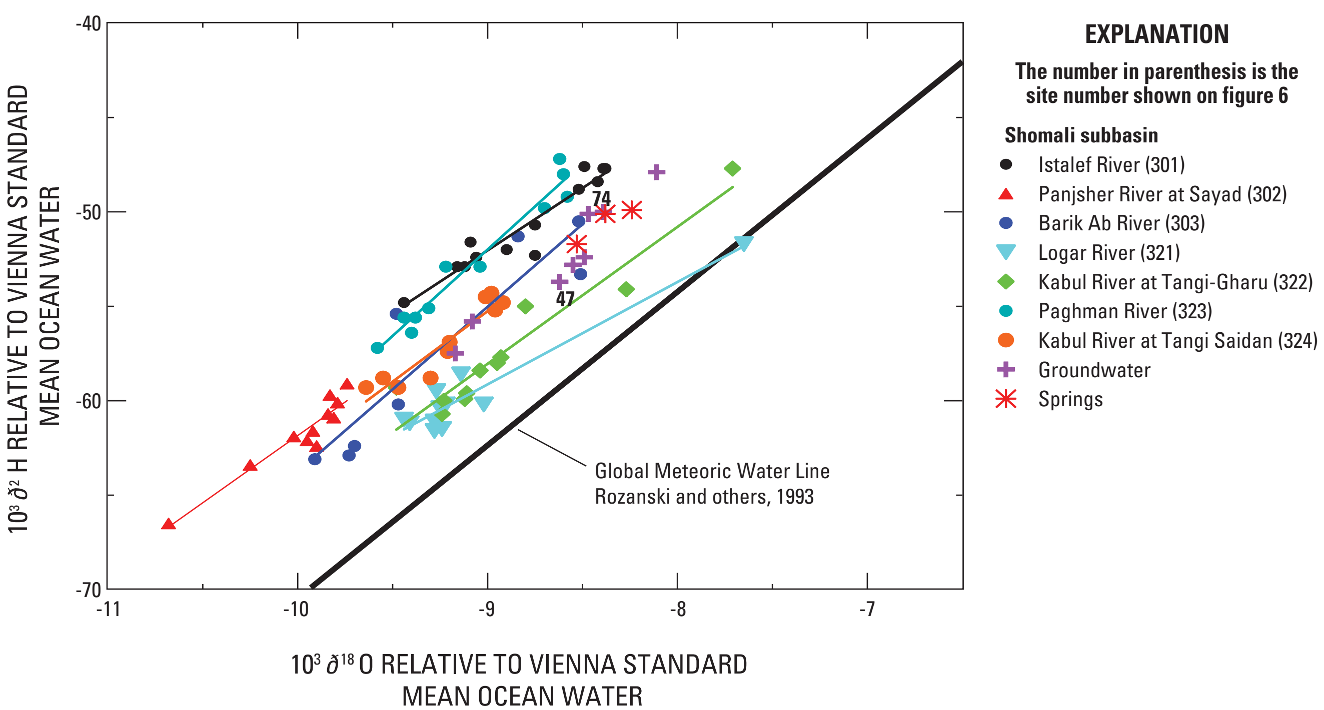

Figure 11-4. The relation between hydrogen and oxygen isotopic composition, relative to Vienna Standard Mean Ocean Water (VSMOW), of all surface waters and of groundwaters and springs in the Shomali subbasin.

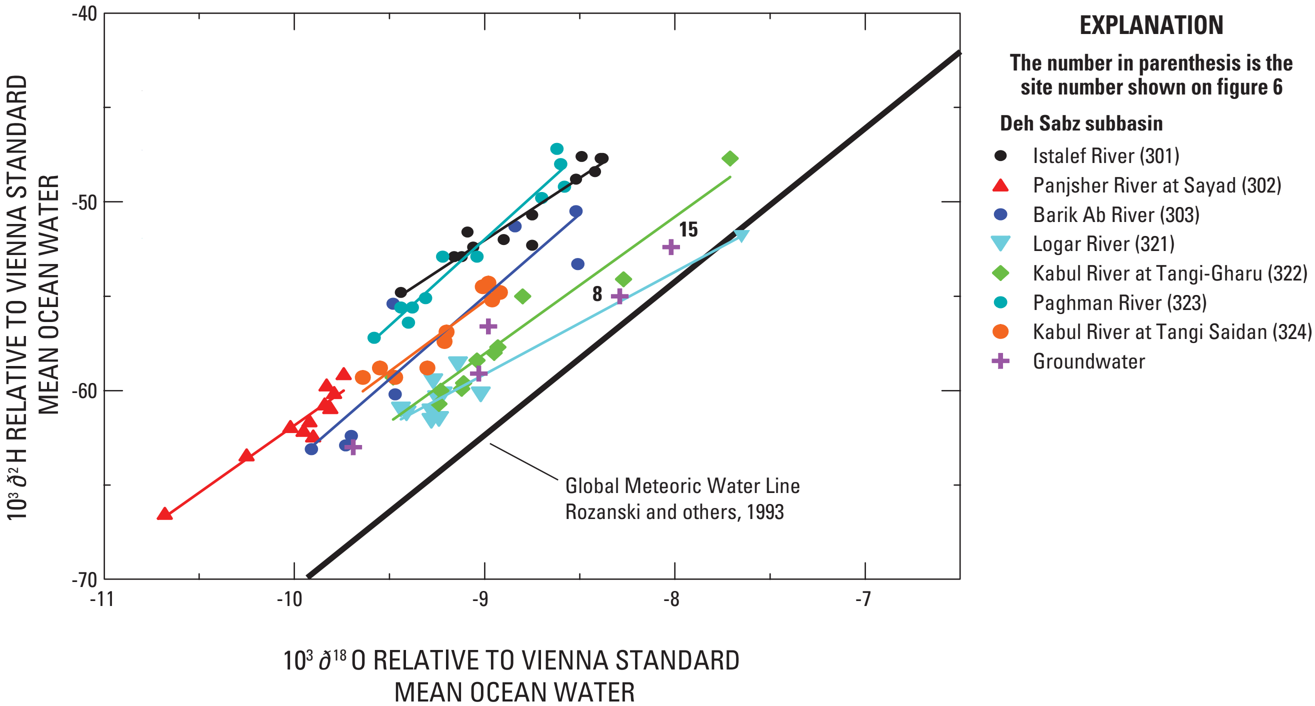

Figure 11-5. The relation between hydrogen and oxygen isotopic composition, relative to Vienna Standard Mean Ocean Water (VSMOW), of all surface waters and of groundwaters and springs in the Deh Sabz subbasin.

Eastern Front

The groundwater, karez, and spring sites in the Eastern Front Source Area are comprised of wells 2.1, 7, 59.1, 71 (Azizi Hotak tank), karez N6, karez 10, karez 69.1, and spring 66.1 (figs. 1 and 6). Samples from these sites had 10^3 *d* values ranging from 18.3 to 21.44. These are expected to be runoff water, such as rain and snowmelt water from the Kohe Safi (fig. 1). These sites are representative of the most arid regions in the Kabul Basin with relative humidity values likely below 70 percent.

The chloride mass concentrations of most of the samples of Eastern Front Source Area were less than 30 mg/L. However, the concentration in well 2.1 was 706 mg/L. If chloride were concentrated in well 2.1 by evaporation, one would expect to observe a strong enrichment in ^{2}H and ^{18}O, but figure 11-6 shows no substantial enrichment in these isotopes, ruling out evaporative enrichment as a mechanism to explain this high chloride concentration.

Paghman and Upper Kabul Subbasin

The groundwater and karez sites in the Paghman and Upper Kabul subbasin are comprised of wells 107, 112, 113, 115, 117, 182, 184, 211, 212, 213, 214, 216, 217, and 222 (Afshar 6B) and karez 105 (figs. 1 and 6). Samples from these sites had 10^3 *d* values ranging from 12.5 to 16.1, except for values greater than 7.77 for wells 115 and 182 (fig. 11-7). Except for wells 115 and 182, these groundwaters had δ^2H and δ^{18}O values that were near to those of the Kabul River at Tang-i-Gharu, in good geographic accord. The source of water for wells 115 and 182 appears to be runoff water, such as rain and snowmelt water, similar to that of the Western and Eastern Front Source Areas, based on 10^3 *d* values greater than 17.34. Precipitation in mountains to the west or south are potential sources for these groundwaters. Karez 105 was highly enriched in ^{2}H and ^{18}O (fig. 11-7) and appears to be a highly evaporated water, not unexpected for a karez.

The chloride mass concentration of the sample from the Kabul River at Tang-i-Gharu was 11 mg/L at high stage when most groundwater recharge is expected. The chloride mass concentrations in samples of groundwater from the Paghman and Upper Kabul area typically were less than 30 mg/L. However, that of well 184 was 103 mg/L. If chloride were concentrated in well 184 by evaporation, a strong enrichment in ^{2}H and ^{18}O would be expected, but figure 11-7 shows no substantial enrichment in these isotopes, ruling out evaporative enrichment as a mechanism to explain this high chloride concentration.

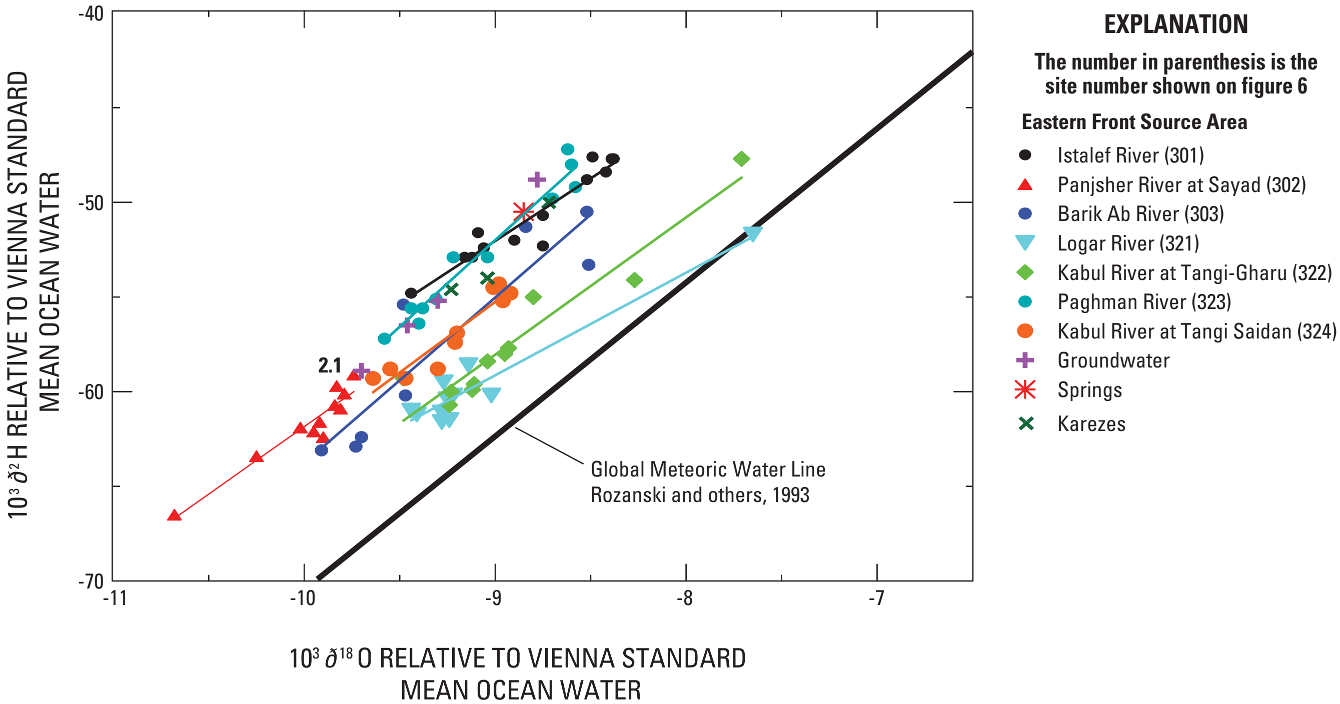

Figure 11-6. The relation between hydrogen and oxygen isotopic composition, relative to Vienna Standard Mean Ocean Water (VSMOW), of all surface waters and of groundwaters and springs in the Eastern Front Source Area.

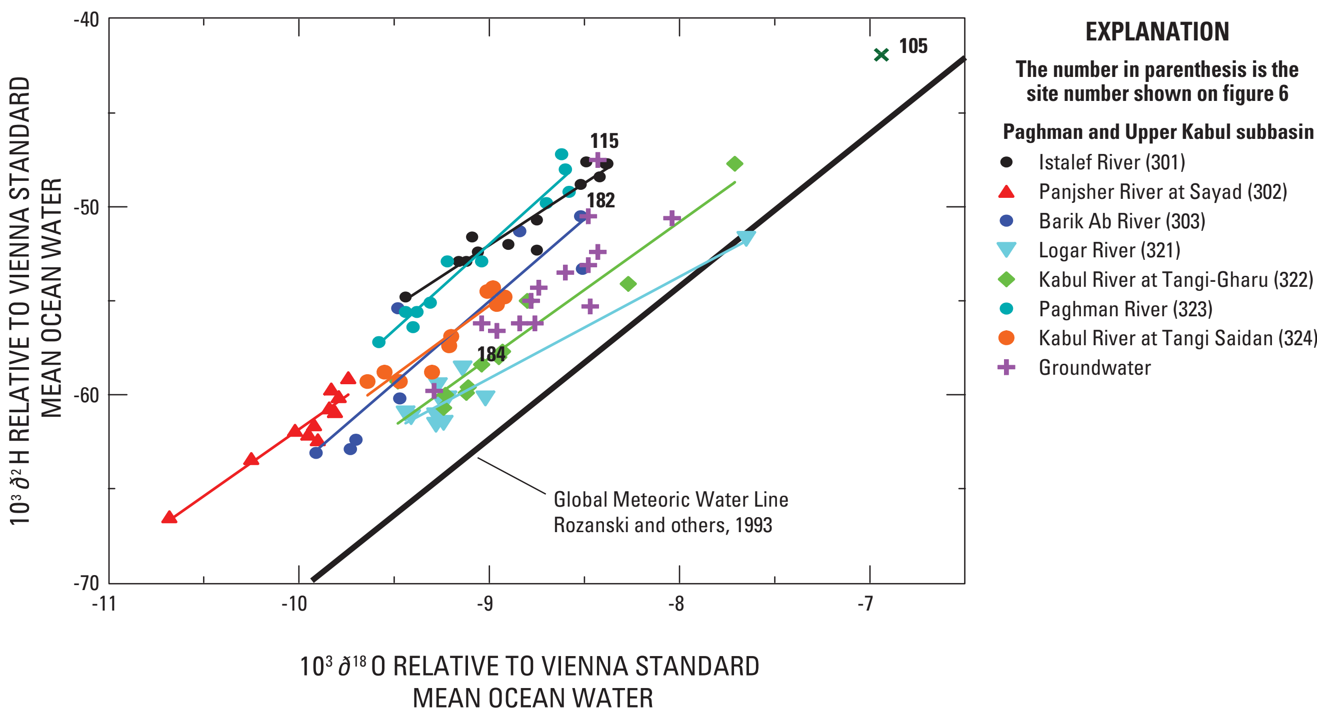

Figure 11-7. The relation between hydrogen and oxygen isotopic composition, relative to Vienna Standard Mean Ocean Water (VSMOW), of all surface waters and of groundwaters and springs in the Paghman and Upper Kabul subbasin.

Central Kabul

The groundwater and spring sites in the Central Kabul subbasin are comprised of wells 64, 65, 124, 129, 133, 148, 152, 153, 156, 157, 162.2, 163, 165, 167, 168, 170, 172, 173, 183 (Hootkhel-Nowbahar pump station), 185, 186, 208, 210, 218, 219, 220, and 223 and spring 180 (figs. 1 and 6). Samples from these sites had $10^3\ \varepsilon_{LC}$ values ranging from –1.2 to 5.8. These sites had δ^2H and δ^{18}O values that are in excellent accord with values of samples from the Kabul River at Tang-i-Gharu (fig. 11-8).

The chloride mass concentrations of groundwater and spring samples ranged from 22 to 1,650 mg/L, as compared to less than 12 mg/L for high stage Kabul River water that could recharge the groundwater system. If chloride were concentrated by evaporation, one would expect to observe a strong enrichment in ^{2}H and ^{18}O. The two wells with the highest chloride concentrations on which δ^2H and δ^{18}O measurements were performed are wells 153 and 185 with chloride mass concentrations of 1,650 and 887 mg/L (fig. 11-8). Although the δ^2H and δ^{18}O values of well 153 are among the most positive of Central Kabul subbasin waters, the magnitude of this enrichment in ^{2}H and ^{18}O is such as to effect less than a doubling in chloride concentration. The δ^2H and δ^{18}O values of well 184 show no enrichment in ^{2}H and ^{18}O. Therefore, another mechanism is needed to explain the high chloride concentrations in the many of the Central Kabul subbasin groundwaters.

Logar Subbasin

The groundwater and spring sites in the Logar subbasin are comprised of wells 116, 135, 140, 143, 187 (Hotuk Pump Station), 201, 202, 203, 204, and 221 and spring 181 (Chari Sib Spring) (figs. 1 and 6). Samples from these sites had $10^3\ \varepsilon_{LC}$ values ranging from 0.6 to 5.7. These sites had δ^2H and δ^{18}O values that are in excellent accord with values of samples from the Logar River (fig. 6), strongly suggesting that this groundwater is Logar River recharged water.

The chloride mass concentrations of samples of Logar subbasin groundwater ranged from 63 to 129 mg/L, compared to 19 mg/L for high-stage Logar River water when most groundwater recharge is expected. Well 116 had the highest chloride mass concentration (129 mg/L) of the Logar subbasin groundwaters. If chloride were concentrated in well 116 by evaporation, a strong enrichment in ^{2}H and ^{18}O would be expected. However, figure 11-9 shows no substantial enrichment in these isotopes in well 116, ruling out evaporative enrichment as a mechanism to explain this high chloride concentration.

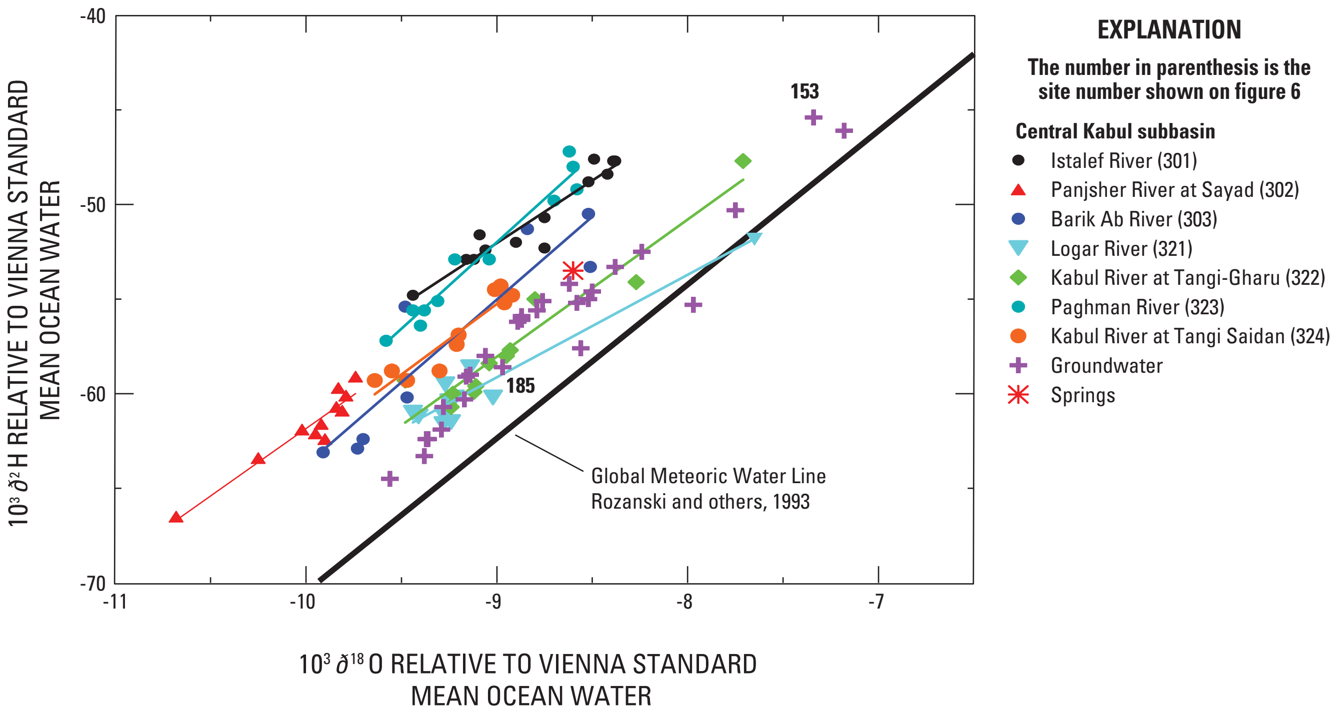

Figure 11-8. The relation between hydrogen and oxygen isotopic composition, relative to Vienna Standard Mean Ocean Water (VSMOW), of all surface waters and of groundwaters and springs in the Central Kabul subbasin.

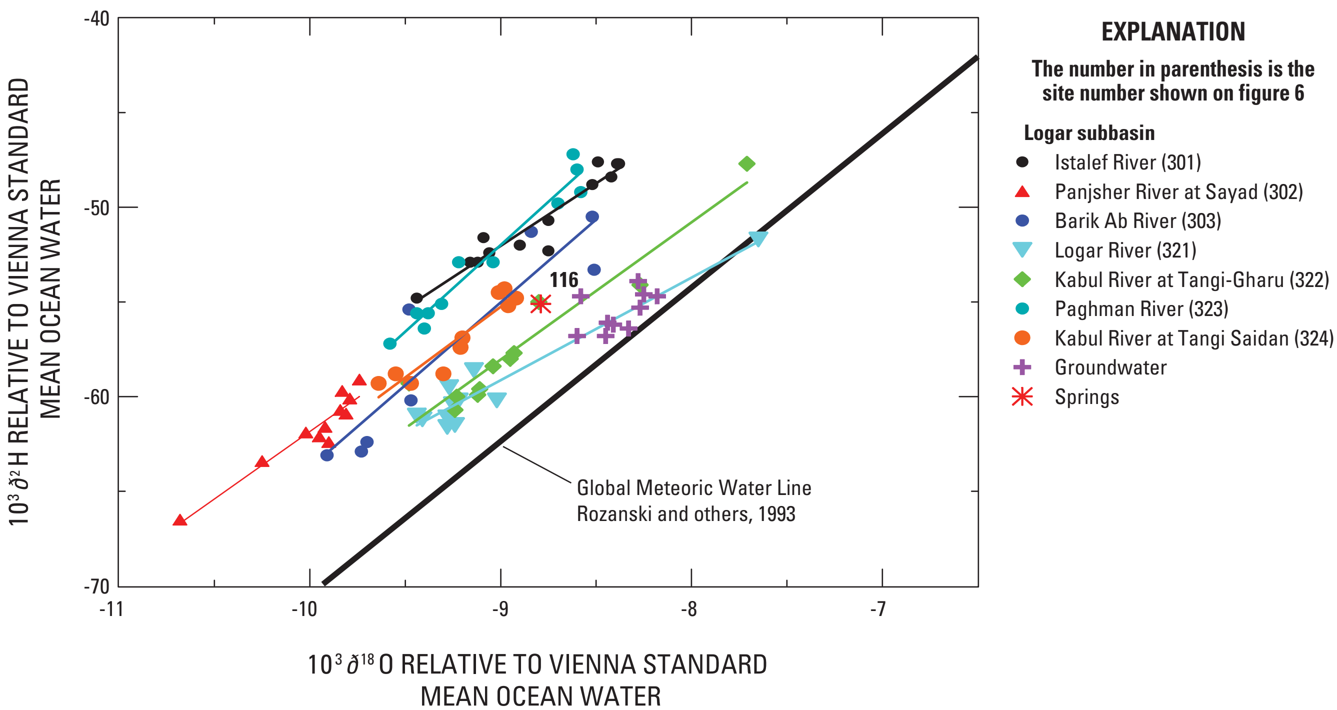

Figure 11-9. The relation between hydrogen and oxygen isotopic composition, relative to Vienna Standard Mean Ocean Water (VSMOW), of all surface waters and of groundwaters and springs in the Logar subbasin.

Summary Observations from Stable-Isotope Data

Several conclusions can be drawn from the stable-isotope data of groundwater and surface water in the Kabul Basin.

1. On the basis of the stable hydrogen and oxygen isotopic compositions, the seven surface-water sites repetitively sampled in this study fall into four distinguishable groups.

    a. The Istalef River and the Paghman River samples had overlapping isotopic compositions and reflected a precipitation source in an arid environment; their source had the lowest relative humidity (approximately 70 percent) of the four groups.

    b. The Kabul River at Tang-i-Saidan and the Barik Ab River near Bagram samples formed the second distinguishable region, but the sources areas were geographically distinct.

    c. The Kabul River at Tang-i-Gharu and the Logar River subbasin samples formed the third distinguishable source.

    d. The fourth distinguishable source was characterized by Panjsher River samples.

2. The stable hydrogen and oxygen isotope record of IAEA precipitation from Kabul, collected between 1962 and 1989 (with clearly evaporated samples removed), agrees well with that of samples from the Istalef River and the Paghman River, whose source or sources had the lowest relative humidity in the Kabul Basin.

3. Stable hydrogen and oxygen isotopic compositions of surface waters indicate no substantial evaporation.

4. None of the groundwater show substantial evaporation in this arid basin except for a single karez.

5. The groundwater, karez, and spring sites can be divided on the basis of their stable isotopic composition into seven groundwater source areas.

    a. Western Front Source Area. This groundwater appears to be runoff water, such as rain and snowmelt water from the Paghman Mountains. The relative humidity of the source area or areas is among the lowest in the area (approximately 70 percent).

    b. Shomali subbasin. This groundwater was not recharged from modern Istalef River water based on isotopic grounds, but from a source having relative humidity higher than ~70 percent.

c. Deh Sabz subbasin. The δ^2H and δ^{18}O values of this groundwater plot closest to those of Kabul River at Tang-i-Gharu and Logar River surface water. Some groundwater may flow through gaps in interbasin ridges from the Central Kabul subbasin to the Deh Sabz subbasin.

d. Eastern Front Source Area. The origin of this water, adjacent upland montains, is similar to that of the Western Front Source Area. The relative humidity of the source area is among the lowest in the region (approximately 70 percent).

e. Paghman and Upper Kabul subbasin. Except for wells 115 and 182, this groundwater has δ^2H and δ^{18}O values that are near to those of the Kabul River at Tang-i-Gharu surface water, in good geographic accord.

f. Central Kabul subbasin. This groundwater has δ^2H and δ^{18}O values that are in excellent accord with those of the Kabul River at Tang-i-Gharu surface water, the presumed source.

g. Logar subbasin. This groundwater appears to be derived from the Logar River on the basis of the similarity of the δ^2H and δ^{18}O values.

6. A small fraction of wells throughout the Kabul Basin have chloride concentrations a factor of 10 to at least 50 higher than their presumed source water. The lack of substantial enrichment in ^{2}H and ^{18}O in these higher chloride waters indicates that evaporation did not cause this chloride enrichment.

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Appendix 12. Water Chemistry, Geochemical Reactions, and Solute Origins

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Appendix 12. Water Chemistry, Geochemical Reactions, and Solute Origins

Most of the groundwater samples collected as a part of this investigation were from relatively shallow sources (depths of 5–185 m, median depth of 48 m (data provided in appendix 10). Deeper wells drilled by the former USSR in the 1970s, known as PASSPORT wells, have depths of 172 to 654 m (median depth of 267 m), and one recently drilled test well (Japan International Cooperation Agency, TW-1) reaches a depth of 640 m (Japan International Cooperation Agency, 2007a, b). The compositions of these waters from relatively deep sources are compared and contrasted with the relatively shallow groundwater samples of this study in figure 12-1. The dissolved solute concentrations of the deep and shallow groundwater samples overlap but tend to be somewhat more elevated in the deep samples than in the shallow groundwater samples. The maximum and median chloride mass concentrations of the shallow wells were nearly 4,190 and 56 mg/L in groundwater in the Kabul Basin (Central Kabul subbasin), and the maximum and median chloride concentrations of the deeper PASSPORT and JICA TW-1 samples were 7,091 and 237 mg/L, respectively. The origin/source/cause of the elevated solute concentration of groundwater of the Kabul Basin needs to be understood in order to distinguish recharge sources to the Basin. Several hypotheses for the origin of the elevated solute concentration were considered: (1) evaporation of surface water (2) geochemical water-rock reactions, (3) dissolution of salts precipitated from evaporation of surface water, (4) upward leakage of (presumed) deep saline water, and (5) water uptake by vegetation.

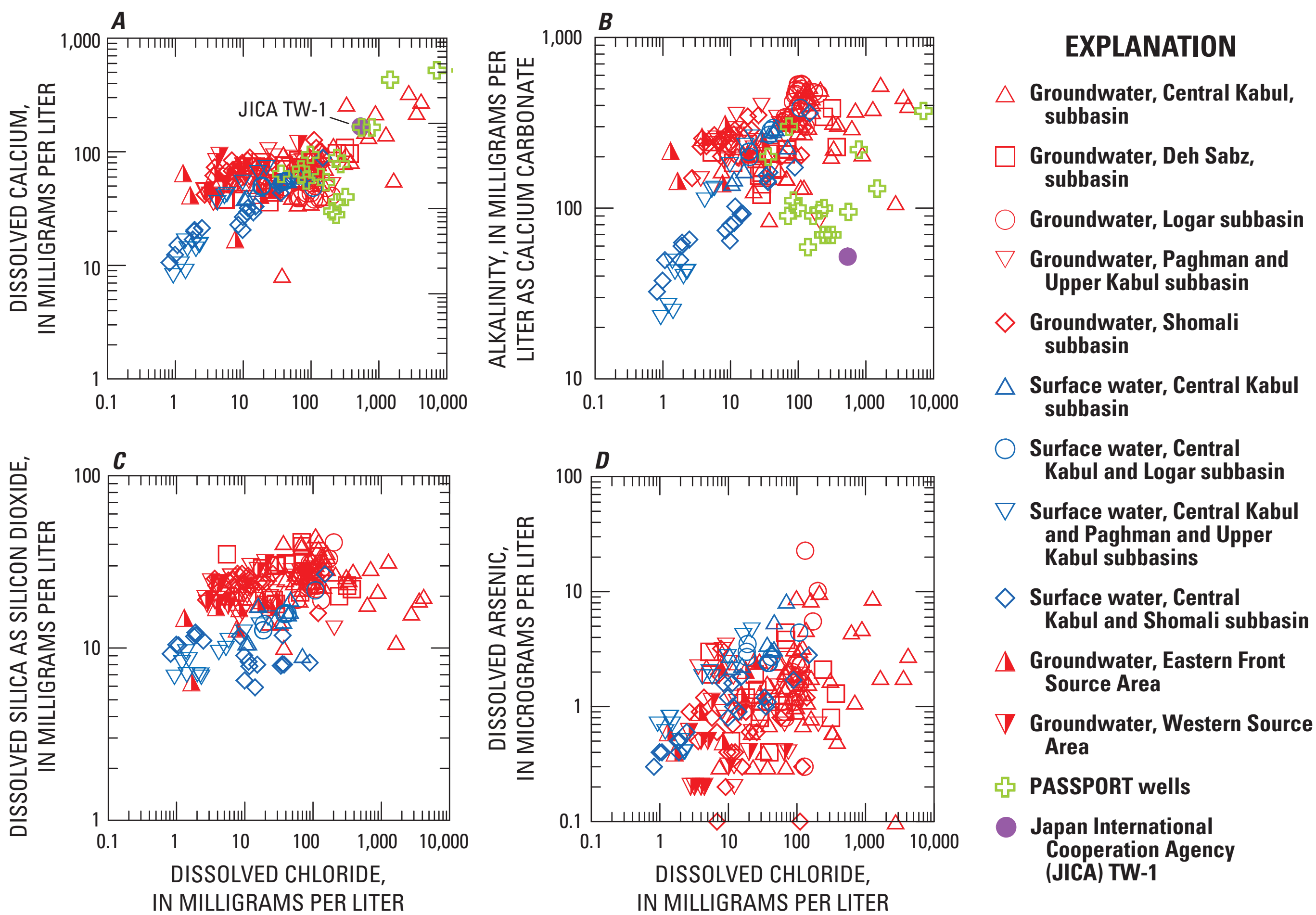

Figure 12-1. Mass concentrations of dissolved (A) calcium, (B) alkalinity as $CaCO_3$, (C) silica, and (D) arsenic in surface water and groundwater from the Kabul Basin as a function of dissolved chloride mass concentration. It is likely that $CaCO_3$ precipitated in bottles prior to determination of alkalinity for many of the PASSPORT water samples, and for water from the Japan International Corporation Agency TW-1 sample.

Solute Ratios

The average ratios of the mass concentrations of some of the major dissolved solutes (particularly Na and SO_4, and to some extent that of Mg) to that of dissolved chloride in groundwater are near those average ratios in surface water for the subbasin and plot along mass concentration trend lines similar to that of surface water (fig. 12-2). This pattern of solute mass concentrations relative to dissolved chloride (fig. 12-2) observed in the relatively shallow groundwater samples (median depth 48 m) of this study continues to waters of more that 650 m depth in the Kabul Basin (Japan International Cooperation Agency, 2007a, b). The similarity in solute ratios in surface water and groundwater for Na/Cl, SO_4/Cl and to some extent Mg/Cl suggests a surface-water source for groundwater with subsequent concentration by evapotranspiration processes. But as explained above in discussion of the stable-isotope data (appendix 11), there is little or no evidence of isotopic fractionation of stable isotopes of water (fig. 12-3), and it is unlikely that evaporative concentration of surface water can be invoked to explain the elevated dissolved solute concentrations. More likely, the water is removed by the non-fractionating process of transpiration by plants.

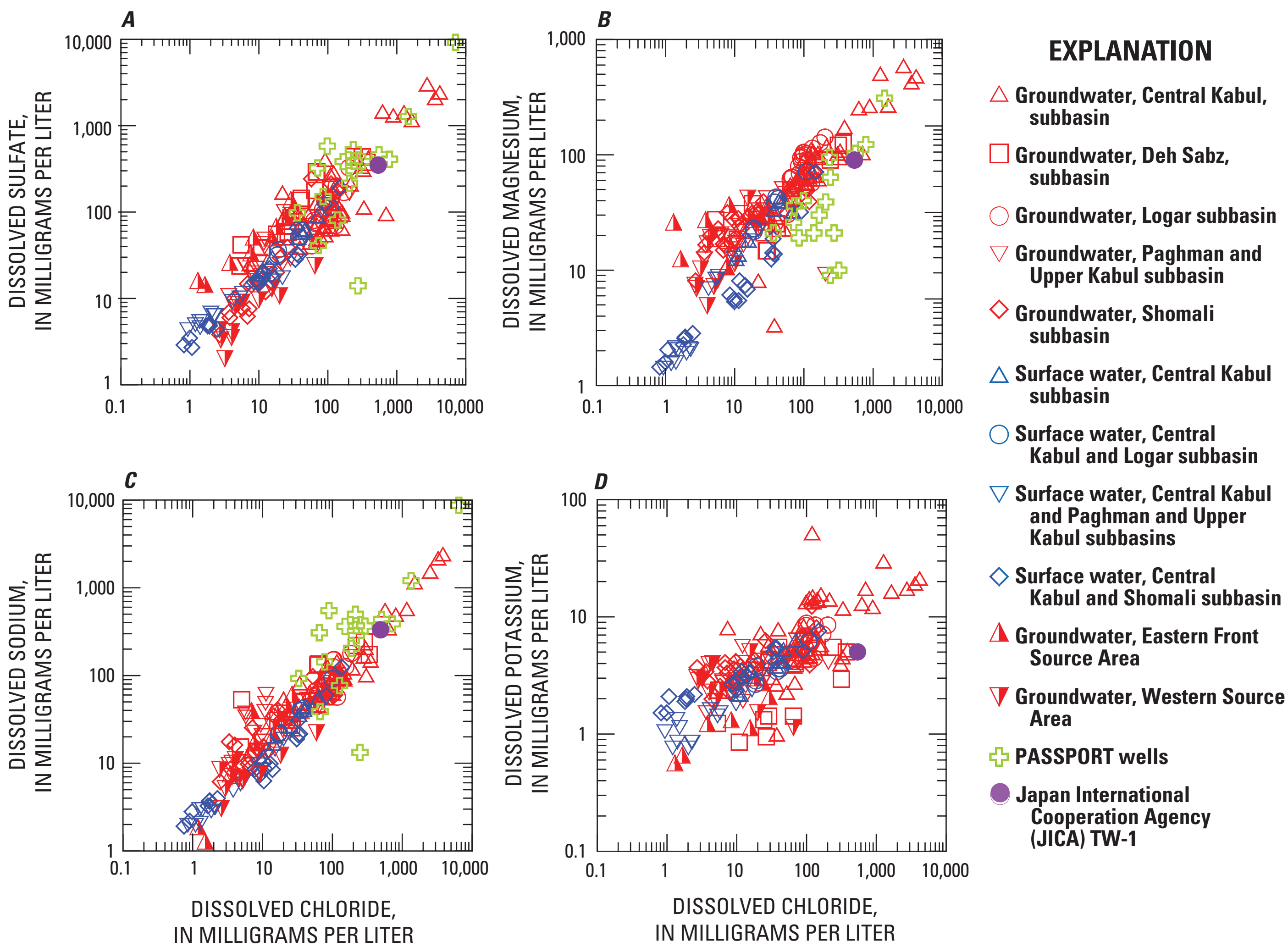

Figure 12-2. Mass concentrations of dissolved (A) sulfate, (B) magnesium, (C) sodium, and (D) potassium in surface water (blue), shallow groundwater (red), and deep groundwater (green and purple) from the Kabul Basin as a function of dissolved chloride mass concentration. The PASSPORT wells in (C) show the quantity Na+K; K was not determined separately for water from the PASSPORT wells. (This figure is the same as figure 24).

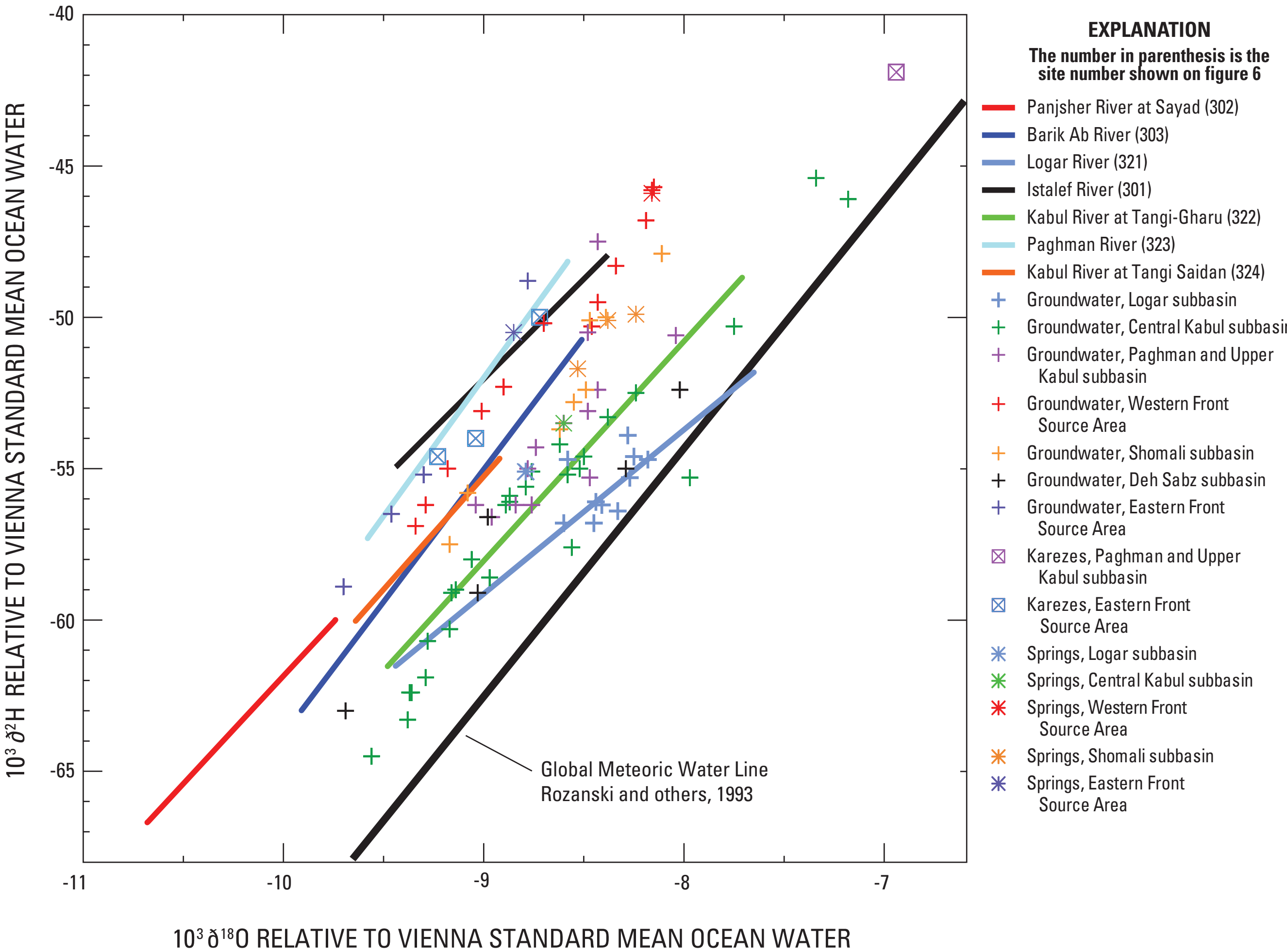

Figure 12-3. The hydrogen versus oxygen isotopic composition of surface water, groundwater, and water from karezes and springs in the Kabul Basin, Afghanistan. (This figure is the same as figure 23).

Conservative Solutes

Because the average ratios of mass concentrations of sodium, sulfate, and to some extent magnesium to chloride are similar to those average mass concentration ratios in surface water, it is unlikely that dissolution of evaporative salts would result in the same solute ratios (fig. 12-2). Other geochemical processes also appear not to affect the water chemistry. For example, the linear relation between dissolved chloride and sulfate (fig. 12-2A) eliminates, for most of the samples, reactions that can remove sulfate (such as microbially mediated sulfate reduction) or add sulfate (oxidation of sulfide minerals, dissolution of gypsum). One sample from a deep PASSPORT well (fig. 12-2A) may have undergone sulfate reduction, lowering the sulfate to chloride ratio in that sample. Waters from JICA TW-1 and the PASSPORT wells are similar in ratio and solute concentration to many of the relatively shallow groundwater samples of the Kabul Basin (fig. 12-2). The dissolved magnesium to chloride relation in groundwaters and surface waters (fig. 12-2B) indicates that dolomite dissolution is probably not an important water-rock reaction in groundwaters of the Kabul Basin, otherwise, the Mg/Cl ratio (ratio of Mg mass concentration to Cl mass concentration) would increase with dissolved chloride concentration along a trend line exceeding that for the surface waters. However, some small differences in the magnesium-chloride concentrations of surface waters probably reflect differences in mineralogy in the source areas (fig. 12-2B). The linear relation of magnesium to chloride in groundwaters suggests that there are no important geochemical reactions that add or remove magnesium from the shallow groundwater and most of the deep groundwater samples (fig. 12-2B). However, approximately half of the PASSPORT samples have somewhat lower Mg/Cl ratios than observed in the JICA TW-1 sample and in the more shallow Kabul Basin samples. These waters may have a different origin or may be affected by geochemical processes that remove Mg from groundwater, because of dolomitization or cation-exchange reactions. However, the linear relation in dissolved sodium and chloride (fig. 12-2C) indicates that cation exchange is not a major water-rock reaction in the region. Most of the potassium concentrations are similar to those of surface waters, or conservatively concentrated surface waters, eliminating possible water-rock reactions involving potassium in forming groundwater compositions (fig. 12-2D). Other dissolved solutes in groundwaters that show nearly constant ratios to dissolved chloride include bromide, boron, and strontium, suggesting little or no water-rock reaction involving these solutes.

Reactive Solutes

Several other dissolved solute to dissolved chloride ratios suggest some geochemical reactions may be occurring, but these cannot account for the elevated solute concentrations. Somewhat elevated calcium, magnesium, and alkalinity relative to chloride in some of the more dilute groundwater samples suggest dissolution of dolomite (figs. 12-2B and 12-1A,B) may occur in some samples. Lower calcium and alkalinity concentrations with increasing dissolved chloride concentration suggest precipitation of calcium carbonate (most likely calcite) (fig. 12-1A,B) in some samples. Most of the groundwater has elevated silica concentrations relative to that of surface water as a function of dissolved chloride (fig. 12-1C) reflecting, possibly, dissolution of primary silicate minerals or other siliciclastics that are abundant in the rocks and alluvial deposits of the Kabul Basin. Most of the dissolved arsenic concentrations in groundwater are less than those of surface water as a function of dissolved chloride (fig. 12-1D). If surface water is the primary source of arsenic to groundwater, arsenic appears to be partially removed by geochemical processes in the groundwater environment—probably by sorption on iron-manganese oxyhydroxides. The presence of dissolved oxygen in many of the groundwater samples and lack of evidence of sulfate reduction suggest removal of arsenic as sulfides is not occurring. A few other reactions are noted from comparing solute concentrations to dissolved chloride, and these include limited formation of barite and fluorite in the more concentrated samples, a lowering of dissolved lithium in some waters from the Deh Sabz region, and a lowering of dissolved manganese concentrations relative to chloride in some waters, presumably because of the formation of iron-manganese oxyhydroxides.

Tritium and Chlorofluorocarbons

Relatively few of the samples analyzed for dissolved solutes were analyzed for chlorofluorocarbons and tritium (43 total), and of these, all samples contained CFCs and tritium (fig. 12-4); even those samples with nearly 2,000 mg/L of dissolved chloride contained CFCs and tritium. Most of the groundwater samples had CFC-12 volume fractions consistent with recharge of post-1970s water (fig. 12-4A). Leakage of saline waters into the basin as a source of the elevated solutes is unlikely because the saline source, being presumably from old deep-basin groundwater, would have to contain major amounts of tritium and chlorofluorocarbons, which is unlikely for old groundwater. Further, the saline water would have to have cation/anion mass ratios similar to that of the surface waters. Still, the possibility of mixtures of old, tracer-free saline water with a young fraction cannot be completely ruled out, though both fractions would have to have similar cation/anion mass ratios.

Uptake of Water by Vegetation (Transpiration)

It appears that the source of solutes in most of the sub-regions of the Kabul Basin was surface water, as supported further by the stable-isotope data (appendix 11). Many of the groundwater samples had solute concentrations that exceeded those measured in surface water by factors of as much as 100 or more. However, these samples were not likely evaporated because there was no evaporative trend in stable-isotope composition (figs. 11-3 to 11-9). Apparently, the elevated solute concentration of the groundwater can be attributed to transpiration along the rivers and surface-water drainage, and near irrigated crop land, wherever plant root systems can reach the water table. Because all the groundwater samples contained CFCs and tritium, even those with dissolved chloride mass concentrations of as much as 2,000 mg/L, the transpiration process is widespread in irrigated areas where most of the wells sampled for this study are located and is occurring on the anthropogenic timescale (the past 60 years). On the basis of the chemical, stable-isotope, and environmental-tracer data, it is concluded that infiltration of surface water, with subsequent concentration through transpiration, was the most likely source of recharge for most of the groundwater of the various subbasins of the Kabul Basin sampled as a part of this investigation. In irrigated agricultural areas where pumps are used to extract groundwater, water may be utilized through multiple cycles of pumping, irrigation, and return flow to the water table, further elevating the dissolved solute concentration. Table 6 summarizes average solute concentrations, stable isotope data, and tritium data for groundwater from the seven groundwater regions and compares average solute concentrations in groundwater to average values from surface water in each region. The average values of specific conductance of groundwater were 2,200, 1,150, 500, 1,300, 700, 700, and 500 μS/cm at 25°C for the Central Kabul subbasin, Deh Sabz subbasin, Eastern Front Source Area, Logar subbasin, Paghman and Upper Kabul subbasin, Shomali subbasin, and Western Front Source Area, respectively. The average values of specific conductance of surface water for the Central Kabul, Logar, Paghman and Upper Kabul, and Shomali subbasins were about 660, 660, 290, and 320, respectively (no surface-water samples were obtained from the Deh Sabz subbasin). The average surface-water solute mass concentrations are increased during irrigation and infiltration cycles relative to those of local surface water by factors of 3.3, 1.9, 2.5, and 2.2 for the Central Kabul, Logar, Paghman and Upper Kabul, and Shomali subbasins, respectively.

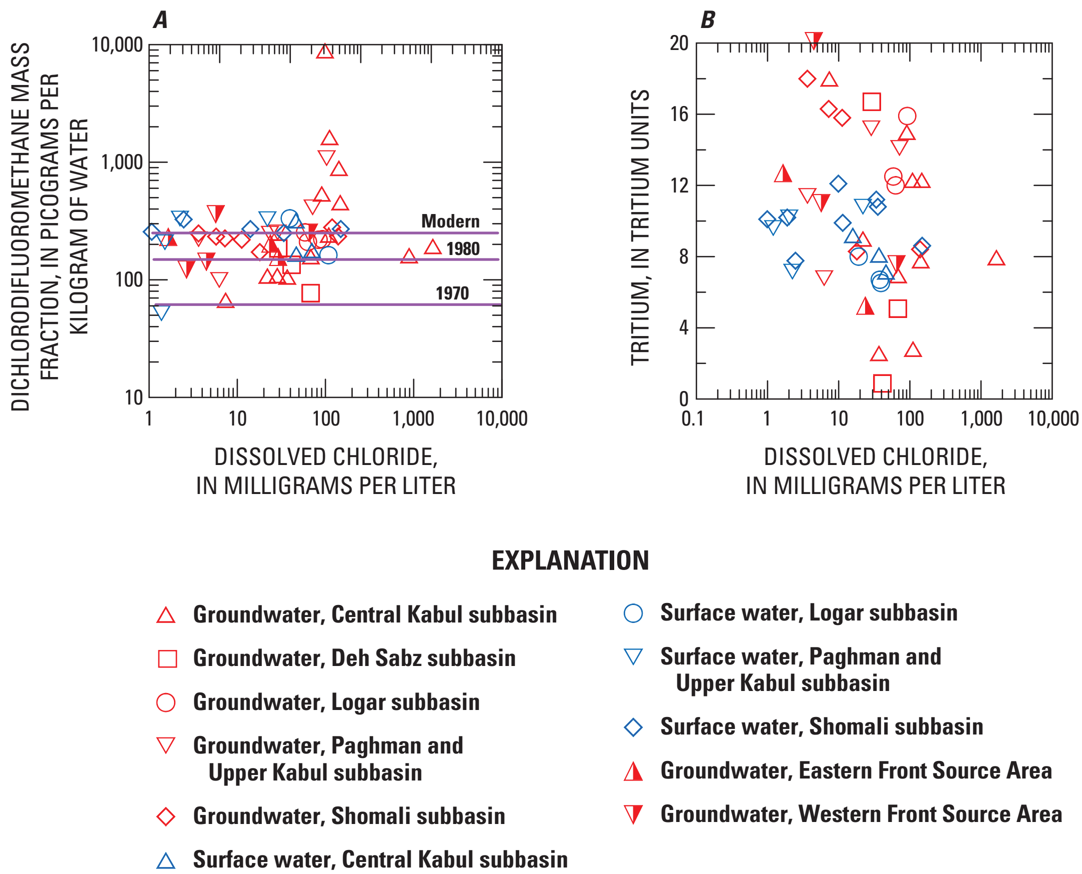

Figure 12-4. Mass fractions of CFC-12 (A) and tritium (B) in surface water and groundwater from the Kabul Basin as a function of dissolved chloride mass concentration.

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Appendix 13. Interpretations of Water Age Based on CFCs and Tritium Data

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Appendix 13. Interpretation of Water Age Based on CFCs and Tritium Data

Age Interpretation

Age interpretation based on CFCs and tritium uses historical records of volume fractions of CFCs in air and of ^3H in local precipitation (fig. 13-1) and depends on choice of the appropriate mixing model to apply to the hydrologic setting. Four hypothetical mixing models were considered—piston flow, exponential mixing, exponential-piston flow, and binary mixing (Cook and Böhlke, 1999). These models commonly describe the range of variations in mixing seen in groundwater environments. Possible mixing relations among the volume fractions of CFC-11, CFC-12, CFC-113 and of ^3H were evaluated by comparing the volume fractions calculated from the measured mass concentrations (table 13-1) with the expected volume fractions according to various mixing models.

Water reaching the open interval of wells with narrow openings or discharging at shallow water-table springs can be nearly uniform in age and can be approximated using a piston-flow model (unmixed water). In this case, amounts of environmental tracer in the water sample closely correspond to amounts in recharge water for the time of recharge. Unmixed samples would have volume ratios close to those of figure 13-1 for the corresponding year of recharge. As tritium undergoes radioactive decay, the sample year is assumed to be 2006, accounting for the decay of tritium in precipitation to the sample year. Exponential mixing can describe discharge from an unconfined aquifer receiving uniform aerial recharge (Eriksson, 1958; Vogel, 1967; Maloszewski and Zuber, 1982; Maloszewski and others, 1983). The exponential model could apply to discharge from wells with relatively large open intervals that integrate a range of water ages or water from springs that discharge from a large groundwater reservoir. The exponential-piston flow model can describe discharge from wells or springs in aquifers, initially unconfined (exponential mixing), that become confined over their aerial extent. In the calculations considered here, the proportion of unconfined and confined aerial extent was assumed to be 1:1, as an example. The binary mixing model applies best in some fractured-rock aquifers where the young (tracer-bearing) component is diluted with old (low- or zero-tracer amount) water. The mean age of the young fraction is calculated from the ratio of the volume fractions of two CFC tracers. The values are calculated from the measured mass concentrations in water and the Henrys Law solubility constant at the altitude and temperature of the sample during recharge. In the case of binary mixing, volume ratios of CFC values define the mean age of the young fraction and, if diluted with old, tracer-free water, the measured CFC mass concentrations can define the fraction of young water in the mixture (International Atomic Energy Agency, 2006).

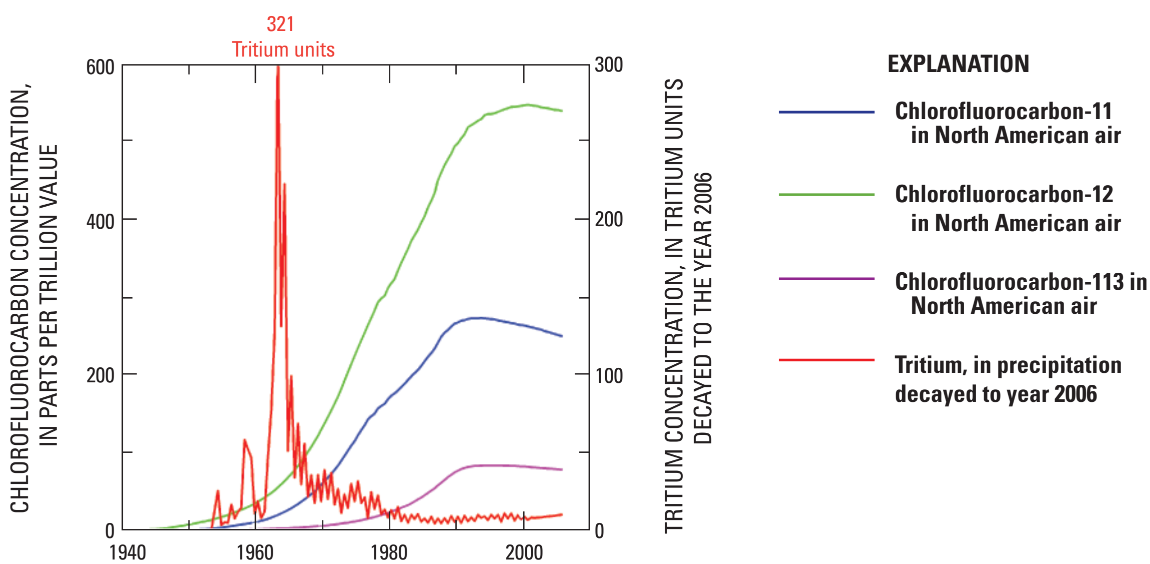


Figure 13-1. Volume fraction of CFCs (CFC-11, CFC-12, CFC-113) in North American (N.A.) air, 1940 to 2007, in ppt, and tritium in precipitation reconstructed for the Kabul Basin and vicinity (see text) decayed to the date, 2006, in tritium units, TU.

Table 13-1. Chlorofluorocarbon and tritium data collected in the Kabul Basin, Afghanistan.

[CFC, Chlorofluorocarbon; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, trichlorotrifluoroethane; pg kg^{-1}, picograms per kilogram; ppt, parts per trillion; TU, Tritium Unit; nd, not determined]

Site number	Name	Groundwater region	Sample date	Sample time	CFC-11 mass fraction [1], pg/kg	CFC-12 mass fraction [1], pg/kg	CFC-113 mass fraction [1], pg/kg	CFC-11 volume fraction [1], ppt	CFC-12 volume fraction [1], ppt	CFC-113 volume fraction [1], ppt	CFC-11 fraction modern [2]	CFC-12 fraction modern [2]	CFC-113 fraction modern [2]	Tritium, in TU
					Groundwater									
13	Pacha Sahab	Deh Sabz	05-16-2006	1200	246.2	184.8	29.6	123.2	395.0	35.4	49.9	73.1	45.5	16.7
28	Obchakan Ball	Shomali	05-23-2006	1300	424.2	218.7	55.6	209.3	460.7	65.6	84.8	85.3	84.5	15.8
33	Mir Afghan	Western Front	05-23-2006	1030	202.7	142.2	20.3	102.7	307.6	24.5	41.6	57.0	31.6	20.1
37	Shekhu	Deh Sabz	05-14-2006	1000	194.8	133.9	32.8	95.9	281.4	38.5	38.8	52.1	49.6	0.9
42	Godar	Shomali	05-28-2006	0810	308.6	171.7	38.6	149.5	355.2	44.7	60.6	65.8	57.6	8.3
47	Dewana	Shomali	05-30-2006	1345	446.6	234.3	54.2	215.2	482.3	62.4	87.2	89.3	80.3	8.4
54	Alghoai	Deh Sabz	05-21-2006	1145	127.6	77.0	16.5	63.8	164.5	19.7	25.9	30.5	25.4	5.1
59.1	Kata Khel	Eastern Front	05-10-2006	1000	245.2	204.5	47.2	123.0	437.8	56.5	49.8	81.1	72.8	5.3
65	Khair Khana	Central Kabul	05-25-2006	0930	194.6	108.1	21.9	98.2	233.0	26.4	39.8	43.1	34.1	9.0
71	Well 71	Eastern Front	06-05-2007	0940	219.6	157.1	36.1	124.8	378.4	49.8	50.0	70.3	63.8	0.4
72	Shakar dara Qalasade-razam	Shomali	06-12-2007	0910	599.6	233.2	61.9	284.7	476.9	69.9	114.1	88.5	89.5	17.4
73	Well 73	Western Front	06-17-2007	1015	232.5	121.8	28.0	101.4	229.2	28.8	40.6	42.5	36.9	8.6
74	Well 74	Shomali	06-19-2007	1140	471.0	279.0	68.6	207.8	529.1	71.5	83.2	98.2	91.5	10.4
104	Dodamast	Western Front	05-13-2006	1100	490.8	250.8	62.2	254.7	555.7	77.2	103.2	102.9	99.4	7.6
105	Karez under Qarga	Paghman and Upper Kabul	05-13-2006	1000	363.7	221.4	47.9	182.4	473.9	57.4	73.9	87.8	73.9	11.4
107	Dashte Karizak	Paghman and Upper Kabul	05-15-2006	1040	191.5	99.5	20.8	98.6	218.6	25.6	39.9	40.5	32.9	6.8
117	Tangi Saedon	Paghman and Upper Kabul	05-15-2006	1220	440.1	252.1	57.3	222.2	543.5	69.1	90.0	100.6	89.0	15.2
129	Kabul Municipality	Central Kabul	05-24-2006	1255	436.5	538.8	42.2	219.1	1,154.5	50.5	88.8	213.8	65.1	15.0
135	Qala-i-Fathulla	Logar	05-17-2006	1050	396.2	221.4	53.1	198.7	473.9	63.6	80.5	87.8	81.9	15.9
153	Parkhae Sonati	Central Kabul	05-20-2006	1305	96.3	193.0	23.6	48.2	412.3	28.2	19.5	76.3	36.4	8.0
165	Qala-i-Baqhalak	Central Kabul	05-22-2006	1000	160.1	1,634.1	14.2	80.2	3,494.4	16.9	32.5	647.1	21.8	2.8
168	Shahrak Police	Central Kabul	05-22-2006	1045	1,562.5	889.7	36.1	782.8	1,903.2	43.2	317.2	352.4	55.6	7.8
172	Share Now	Central Kabul	05-22-2006	1145	221.7	454.7	25.0	111.1	973.1	30.0	45.0	180.2	38.6	12.3
182	Qala Wazir	Paghman and Upper Kabul	06-02-2007	1155	505.8	245.9	60.7	239.3	501.2	68.2	95.9	93.0	87.3	11.5
183	Hoot Khel	Central Kabul	06-04-2007	0905	166.8	8,879.6	27.7	76.7	17,572.0	30.2	30.7	3,262.0	38.6	12.4
184	Dehmazang Pampstion well	Paghman and Upper Kabul	06-06-2007	0920	519.7	1,076.9	30.3	299.9	2,609.1	42.2	120.1	484.3	54.1	10.9

Table 13-1. Chlorofluorocarbon and tritium data collected in the Kabul Basin, Afghanistan.—Continued

[CFC, Chlorofluorocarbon; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, tricllorotrifluoroethane; pg kg^{-1}, picograms per kilogram; ppt, parts per trillion; TU, Tritium Unit; nd, not determined]

Site number	Name	Groundwater region	Sample date	Sample time	CFC-11 mass fraction [1], pg/kg	CFC-12 mass fraction [1], pg/kg	CFC-113 mass fraction [1], pg/kg	CFC-11 volume fraction [1], ppt	CFC-12 volume fraction [1], ppt	CFC-113 volume fraction [1], ppt	CFC-11 fraction modern [2]	CFC-12 fraction modern [2]	CFC-113 fraction modern [2]	Tritium, in TU
					Groundwater—Continued									
185	Karte New	Central Kabul	06-16-2007	1056	269.6	161.2	34.4	135.4	345.7	41.2	54.2	64.2	52.8	2.0
186	Khair Khana	Central Kabul	06-18-2007	0940	208.9	108.6	25.1	129.0	281.0	37.9	51.7	52.2	48.5	0.6
187	Charkh Aab Pum Azizi Hootak	Logar	06-20-2007	1030	264.6	219.1	50.0	96.8	354.0	42.4	38.8	65.7	54.3	8.5
203	Logar	Logar	05-20-2006	1110	378.6	209.6	49.8	189.6	448.1	59.6	76.8	83.0	76.7	12.0
208	Microrayan	Central Kabul	05-20-2006	0930	380.4	241.2	44.0	190.6	516.0	52.7	77.2	95.5	67.9	12.3
213	Alluddin	Paghman and Upper Kabul	05-15-2006	1305	545.0	411.6	61.2	273.7	882.5	73.4	1,10.9	163.4	94.5	14.1
219	Khair Khana part 2	Central Kabul	05-24-2006	0935	159.5	105.9	19.8	80.1	227.2	23.8	32.5	42.1	30.6	2.6
221	Bagrami Well 221	Logar	02-19-2007	1120	223.8	149.6	22.9	110.5	316.1	27.0	44.8	58.5	34.7	6.8
223	US Embassy cafe well	Central Kabul	02-22-2007	1400	130.0	158.1	12.2	64.4	333.5	14.3	26.1	61.8	18.5	7.0
			Average		343.6	542.5	38.0	170.9	1,123.4	44.8	69.0	208.3	57.6	9.4
			Standard Deviation		252.9	1,483.7	16.2	127.1	2,944.3	18.4	51.4	546.6	23.6	5.1
			Median		264.6	218.7	36.1	129.0	448.1	42.4	51.7	83.0	54.3	8.6
			Maximum		1,562.5	8,879.6	68.6	782.8	17,572.0	77.2	317.2	3,262.0	99.4	20.1
			Minimum		96.3	77.0	12.2	48.2	164.5	14.3	19.5	30.5	18.5	0.4
					Springs									
66.1	Deh Sabz Khaas Spring	Eastern Front	05-16-2006	1110	322.0	232.5	41.7	161.4	497.7	50.0	65.4	92.2	64.4	12.7
67.1	Istelef Spring	Shomali	05-23-2006	1145	382.9	247.5	48.5	192.0	530.0	58.1	77.8	98.1	74.8	18.0
68.1	Gaza Spring	Shomali	05-21-2006	1000	473.0	225.0	59.5	237.2	481.8	71.3	96.1	89.2	91.9	16.3
101	Chandal Bai Spring	Western Front	05-13-2006	1130	751.9	360.2	67.9	377.0	771.3	81.3	152.8	142.8	104.7	11.0
180	Khaja Safa Spring	Central Kabul	06-17-2006	0945	4.9	67.2	2.4	2.5	143.9	2.9	1.0	26.6	3.7	18.0
181	Chara Sib Spring	Logar	06-17-2006	1135	407.0	252.6	57.7	204.1	540.9	69.1	82.7	100.2	89.0	12.5
			Average		390.3	230.9	46.3	195.7	494.3	55.4	79.3	91.5	71.4	14.8
			Standard Deviation		241.3	94.1	23.3	121.0	201.5	27.9	49.0	37.3	36.0	3.1
			Median		394.9	240.0	53.1	198.0	513.9	63.6	80.2	95.1	81.9	14.5
			Maximum		751.9	360.2	67.9	377.0	771.3	81.3	152.8	142.8	104.7	18.0
			Minimum		4.9	67.2	2.4	2.5	143.9	2.9	1.0	26.6	3.7	11.0

Table 13-1. Chlorofluorocarbon and tritium data collected in the Kabul Basin, Afghanistan.—Continued

[CFC, Chlorofluorocarbon; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, tricllorotrifluoroethane; pg kg^{-1}, picograms per kilogram; ppt, parts per trillion; TU, Tritium Unit; nd, not determined]

Site number	Name	Groundwater region	Sample date	Sample time	CFC-11 mass fraction [1], pg/kg	CFC-12 mass fraction [1], pg/kg	CFC-113 mass fraction [1], pg/kg	CFC-11 volume fraction [1], ppt	CFC-12 volume fraction [1], ppt	CFC-113 volume fraction [1], ppt	CFC-11 fraction modern [2]	CFC-12 fraction modern [2]	CFC-113 fraction modern [2]	Tritium, in TU
Surface water														
301	Istalef River	Shomali	2-13-2007	1145	637.7	326.2	89.1	242.7	551.3	79.4	98.4	102.1	102.3	7.8
302	Panjshir River at Sayad	Shomali	02-06-2007	1130	504.7	250.1	64.0	227.9	490.2	69.1	92.4	90.8	89.0	11.2
303	Barak Ab River	Shomali	02-20-2007	1020	494.2	269.9	67.0	218.5	519.1	70.7	88.6	96.1	91.0	8.6
321	Logar River	Logar	02-07-2007	1100	622.8	332.6	84.5	228.0	542.7	72.3	92.4	100.5	93.1	6.5
322	Kabul River at Tangi Gharu	Central Kabul	02-07-2007	1300	700.6	319.2	82.0	285.3	572.7	78.8	115.6	106.0	101.4	7.2
323	Paghman River at Pagh-man	Paghman and Upper Kabul	02-10-2007	1350	688.9	331.1	92.6	247.6	534.7	77.2	100.3	99.0	99.4	7.2
324	Kabul River at Tang-i Saidan	Paghman and Upper Kabul	02-10-2007	1100	656.5	326.7	90.2	236.3	525.5	75.6	95.7	97.3	97.4	10.8
301	Istalef River at Istalef	Shomali	06-14-2007	0920	1,090.0	255.7	72.2	611.7	611.6	98.6	245.1	113.5	126.3	nd
301	Istalef River at Istalef	Shomali	07-15-2007	1000	398.0	201.9	51.0	260.5	554.3	82.5	104.4	102.9	105.6	nd
302	Panjshir River at Sayad	Shomali	06-19-2007	1030	531.8	270.3	71.3	285.7	618.7	93.2	114.5	114.9	119.4	nd
321	Logar River	Logar	06-20-2007	1130	238.5	162.4	32.4	190.6	533.3	65.5	76.4	99.0	83.9	nd
322	Kabul River at Tangi Gharu	Central Kabul	06-04-2007	1115	78.9	178.3	40.0	63.9	592.6	82.2	25.6	110.0	105.2	nd
322	Kabul River at Tangi Gharu	Central Kabul	07-04-2007	0955	363.5	165.6	39.1	298.5	556.9	81.4	119.6	103.4	104.3	nd
323	Paghman River at Pagh-man	Paghman and Upper Kabul	06-02-2007	1030	399.0	208.0	52.3	250.4	553.3	80.3	100.3	102.7	102.8	nd
			Average		528.9	257.0	66.3	260.5	554.1	79.1	104.9	102.7	101.5	8.5
			Standard Deviation		241.3	64.5	20.5	115.9	35.5	8.9	46.3	6.7	11.2	1.9
			Median		518.2	262.8	69.1	245.2	552.3	79.1	99.3	102.4	101.9	7.8
			Maximum		1,090.0	332.6	92.6	611.7	618.7	98.6	245.1	114.9	126.3	11.2
			Minimum		78.9	162.4	32.4	63.9	490.2	65.5	25.6	90.8	83.9	6.5

Table 13-1. Chlorofluorocarbon and tritium data collected in the Kabul Basin, Afghanistan.—Continued

[CFC, Chlorofluorocarbon; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, tricllorotrifluoroethane; pg kg^{-1}, picograms per kilogram; ppt, parts per trillion; TU, Tritium Unit; nd, not determined]

Site number	Name	Groundwater region	Sample date	Sample time	CFC-11 mass fraction[1], pg/kg	CFC-12 mass fraction[1], pg/kg	CFC-113 mass fraction[1], pg/kg	CFC-11 volume fraction[1], ppt	CFC-12 volume fraction[1], ppt	CFC-113 volume fraction[1], ppt	CFC-11 fraction modern[2]	CFC-12 fraction modern[2]	CFC-113 fraction modern[2]	Tritium, in TU
						Air								
181	Chara Sib Spring		12-10-2006	–	–	–	–	281.2	610.1	137.9	112.7	113.3	176.6	–
181	Chara Sib Spring		01-10-2007	–	–	–	–	253.6	542.7	81.4	101.6	100.7	104.2	–
181	Chara Sib Spring		05-29-2007	–	–	–	–	272.1	550.9	94.9	109.0	102.3	121.5	–
181	Chara Sib Spring		06-20-2007	–	–	–	–	494.1	685.0	266.1	197.9	127.2	340.7	–
	Dihsabz-Khas Village		06-03-2007	–	–	–	–	293.5	563.3	108.3	117.6	104.6	138.6	–
	Shomaly Istalef District		06-14-2007	–	–	–	–	418.6	630.4	194.1	167.7	117.0	248.6	–
			Average					335.5	597.1	147.1	134.4	110.8	188.4	
			Standard Deviation					97.5	55.2	70.7	39.0	10.2	90.5	
			Median					287.4	586.7	123.1	115.1	108.9	157.6	
			Maximum					494.1	685.0	266.1	197.9	127.2	340.7	
			Minimum					253.6	542.7	81.4	101.6	100.7	104.2	

[1] Calculated using altitude, recharge temperatures and excess air from Table 13-2.

[2] Assumes CFC-11, CFC-12, and CFC-113 volume fractions in Kabul Basin air in 2006 of 249.6, 538.7, and 78.1 ppt, respectively, based on North American Air (IAEA, 2006).

Several processes may affect the concentrations and interpretation of CFCs and tritium in the Kabul Basin waters. CFCs can degrade microbially in low-oxygen waters. The relative rates of degradation are in the order CFC-11>>CFC-113>CFC-12 (International Atomic Energy Agency, 2006). Consequently, in some low-oxygen samples, there can be an old bias in apparent ages based on CFC-11, whereas apparent ages based on CFC-113 and CFC-12 will be in relatively close agreement. In some cases, there can be other (anthropogenic) sources of CFCs, in addition to that of the atmosphere, such as from some industrial wastewaters (International Atomic Energy Agency, 2006). In this case, water samples may have CFC concentrations greater than that from an atmospheric source, giving a young, or impossibly young, bias.

Mixing relations among the CFC and tritium tracers were examined using tracer-tracer plots. In constructing these plots, it was necessary to assume a recharge temperature and recharge altitude for each water sample in order to calculate CFC volume fractions. For these calculations, the reported sample land-surface altitude was used, or if not available, the median altitude of 1,800 m was used. The recharge temperature determined from measurements of the mass concentrations of nitrogen (N_2) and argon (Ar) dissolved in 16 samples (table 13-2) averaged 12.7 ± 2.5°C; the range was 7.0 to 16.7°C. For CFC-age interpretation, the measured recharge temperature was used if determined; otherwise, the average value was used. Procedures used in evaluating the dissolved-gas compositions are given in Plummer and others (2003) and International Atomic Energy Agency (2006). Most of the water samples analyzed for N_2 and Ar appear to be under somewhat reducing conditions, undergoing denitrification (table 13-2), with as much as 7 mg/L of excess N derived from denitrification of nitrate. However, of the overall data set, including many groundwater samples not analyzed for CFCs, dissolved oxygen mass concentrations averaged 4 to 9 mg/L. Quantities of excess air are estimated to average about 1.1 cc STP per kg. A small correction was applied for the excess air in CFC-age interpretation (International Atomic Energy Agency, 2006).

Atmospheric Input Functions of CFCs and Tritium for the Kabul Basin

In constructing the tracer-tracer plots, atmospheric input functions of CFCs and tritium in precipitation were used to define piston-flow relations (fig. 13-1).

CFCs

The CFC atmospheric input functions were taken as that of North American Air (International Atomic Energy Agency, 2006). Because the CFCs are relatively well-mixed in the Northern Hemisphere in areas remote from urban and industrial centers, this assumption is reasonable and supported by some of the CFC analyses of air from the Kabul Basin (table 13-1). Other samples show an excess of CFCs in Kabul Basin air today. Modern North American air (International Atomic Energy Agency, 2006) has CFC-11, CFC-12, and CFC-113 volume fractions of approximately 250, 539, and 78 ppt. The median CFC-11, CFC-12, and CFC-113 volume fractions in the six Kabul Basin air samples, expressed as a ratio of modern, are 115, 109, and 158 percent, respectively. Today, there appears to be an excess of CFC-113 in local air of the Kabul Basin, though the source is not known. To a lesser extent, there also is an excess of CFC-11 and CFC-12 relative to North American air in the air samples collected from the Kabul Basin (table 13-1).

Tritium

In constructing the "tritium in precipitation" input function for the Kabul Basin, the available GNIP tritium data for Kabul (International Atomic Energy Agency/WMO, 2004) were examined and compared to the IAEA records from Ottawa and Vienna. Correlations were constructed to help fill in gaps in the Kabul record. As has been noted in the past, the Ottawa record contains input from a local tritium source in post-1980 precipitation. The available Kabul tritium data are nearly identical to the Vienna record in the past 20+ years. The "tritium in precipitation" input function used for the Kabul Basin was constructed from a correlation with Ottawa data prior to the early 1960s, uses observed Kabul data where available, uses a correlation with the Vienna record where Kabul data are missing in the post-1960s to mid-1970s, and uses the Vienna record directly in recent years where Kabul data are missing.

CFCs in Groundwater

Among the 41 groundwater samples from wells and springs analyzed for CFCs, the median volume fractions of CFC-11, CFC-12, and CFC-113, expressed as a ratio to that in modern North American air, were 72, 86, and 65 percent, respectively. Six samples had CFC-11 amounts that exceeded equilibrium with modern air; 11 samples had CFC-12 amounts that exceeded equilibrium with modern air values, and one of the CFC-113 values in groundwater exceeded equilibrium with modern air. Excesses of CFC-11 and CFC-12 greater than those of modern air-water equilibrium co-occurred in five of the six samples with CFC-11 amounts being greater than equilibrium with modern air (table 13-1). For the samples that had volume fractions that exceeded those of modern values, the median excesses were factors of 1.2 for CFC-11 and 1.8 for CFC-12 relative to waters in equilibrium with modern air. Of the three CFCs measured, CFC-12 had a higher frequency to exceed air-water equilibrium than did CFC-11 or CFC-113. Only one of the six spring samples had excess CFCs (water from site 101) where the volume fractions of all three CFCs were somewhat elevated above that for modern air-water equilibrium. The median CFC-11, CFC-12, and CFC-113 volume fractions in water from springs were 80, 95, and 82 percent modern, respectively.

CFCs in Surface Water and Air

The median volume fractions of CFC-11, CFC-12, and CFC-113 in the 14 surface-water samples (table 13-1), correcting for altitude and water temperature, were 99, 102, and 102 percent modern, respectively. Apparently, today the local surface waters are near equilibrium with the modern atmosphere, but in the past, there may have been local inputs of CFC-12 (and CFC-11) that exceeded North American air concentrations resulting in enrichment with respect to CFC-12 (and to a lesser extent, CFC-11) in some of the older waters. Alternatively, other land-use activities may have introduced an excess of CFC-12 (and CFC-11) in the past; an activity that is currently limited. Excess of all three CFCs were measured in all six air samples collected in remote regions of the Kabul Basin (table 13-1).

CFC Ages

Two processes have affected CFC-age interpretation in Kabul Basin groundwater: (1) excess CFC sources, in addition to that of the atmosphere in the Kabul region, resulting in CFC excesses in some surface water, and (2) degradation of CFCs, primarily CFC-11. The extent to which any one sample has been affected by one or both of these processes is variable. Evidence of contamination and degradation processes is seen in plots comparing CFC volume fractions in water and air with model calculations (fig. 13-2).

Volume fractions of CFC-11 and CFC-113 are compared in figure 13-2A. Many of the CFC-11 and CFC-113 volume fractions plot along the binary dilution line as if modern water were diluted with old, CFC-free water. Accordingly, seven samples contain an excess of CFC-113 (fig. 13-2A). Alternatively, the CFC-11 volume fractions may be biased low because of microbial degradation. In this case, the CFC-113 values may be in the normal range. Similar interpretation based on CFC-11 and CFC-113 values apply to the surface-water samples, which are either diluted with old, CFC-free water or degraded.

Either most of the samples contain an excess of CFC-12 or most are degraded with regard to CFC-11 (fig. 13-2B). Most of the groundwater samples have CFC-12 and CFC-113 concentrations that plot within the envelope of “normal” values, bounded by model lines of piston flow and binary mixing (fig. 13-2C). Many samples indicate mixtures, and others plot near the piston-flow line (unmixed samples) (fig. 13-2C). Still other samples (groundwater, surface water, and water from springs) plot approximately parallel to results for piston flow but are either degraded in CFC-113 or elevated in CFC-12 (fig. 13-2C). Several lines of evidence point to microbial degradation: (1) most of the samples analyzed for dissolved N_2 and Ar apparently have low dissolved oxygen concentration and have undergone denitrification (table 13-2), though it cannot be determined to what extent the samples were degraded on storage in Afghanistan and during shipment to the Reston Chlorofluorocarbon Laboratory of the U.S. Geological Survey; (2) one sample contains dissolved methane (table 13-2); (3) several surface-water samples are degraded in CFCs, particularly CFC-11 (table 13-2). Still other surface-water and groundwater samples are elevated in CFC-12, so it is likely that both processes have affected some of the samples to varying extents.

The piston-flow ages that could be calculated from the CFC groundwater data are summarized in table 13-3. The median piston-flow ages for CFC-11, CFC-12, and CFC-113 from data from the 34 wells were 31, 24, and 22 years, respectively, with ranges of piston-flow ages of 13 to 38, 9 to 35, and 16 to 31 years, respectively. Dual ages could only be calculated for three samples (wells 13, 104, and 213). All other samples have CFC piston-flow ages older than the turnover in atmospheric CFC input functions (fig. 13-1). These preliminary results suggest little modern water was sampled. Most of the samples either pre-date the turnover in CFC air curves or are dilutions of young water.

Seventeen of the samples had CFC concentrations in the range that permitted evaluation as binary mixtures of young and old water, based on CFC-113 and CFC-12. For these, the average age of the young part was 21 ± 2 years and the fraction of that young water averaged 76 ± 18 percent. Using the ratio of the CFC-113 and CFC-11 volume fractions, the age of the young fraction in 24 samples averaged 16 ± 3 years with a young fraction of 58 ± 22 percent. In both cases, relatively high fractions of young water were indicated with ages of 16 to 21 years.

Age Variations Between Groundwaters

The differences in the average piston-flow ages, the average ratio-based ages, average fraction of young water in mixtures, average fraction of modern water, and average tritium concentration in groundwater from each of the seven sub-regions of the Kabul Basin are relatively small (table 13-4) and similar to the average values for the Kabul Basin. The most reliable ages are judged to be the CFC-12 and CFC-113 piston-flow ages and ratio-based ages determined from the ratios of the CFC-113 and CFC-12 volume-fraction data. The average CFC-12 piston-flow ages ranged from 20 years (Paghman and Upper Kabul subbasin) to 28 years (Deh Sabz and Central Kabul subbasin), and based on CFC-113 range from 19 years (Shomali subbasin) to 26 years (Central Kabul subbasin) (table 13-4). The ratio-based ages are slightly younger than the piston-flow ages and ranged from 15 years (Shomali subbasin) to 23 years (Western Front Source Area) on the basis of the CFC-113/CFC-12 ratio of volume fractions. The percent of young water in those samples modeled as mixtures of young and tracer-free water tends to decrease with depth below the water table; average values ranged from 55 percent (Paghman and Upper Kabul subbasin) to 95 percent (Eastern Front Source Area) (table 13-4). However, the similarity in piston-flow and ratio-based ages supports the conclusion that most of the waters are unmixed, i.e., they are, for the most part, not dilutions of a young fraction. In this case, the piston-flow ages or ages based on the exponential model most likely apply.

Water pumped from relatively large open intervals in alluvial basin-fill sediment may be interpreted best using exponential mixing models. In this case, mean ages derived from the exponential model will be greater than the piston-flow ages in samples where the piston-flow ages are greater than about 10–15 years, as in the present samples. As a guide, selected values of mean exponential age are shown along the exponential model lines in figures 13-2A-C. The exponential-model mean ages appear to range from about 5 to 100 years, but again do not differ greatly between groundwater subbasins and source area (fig. 13-2).

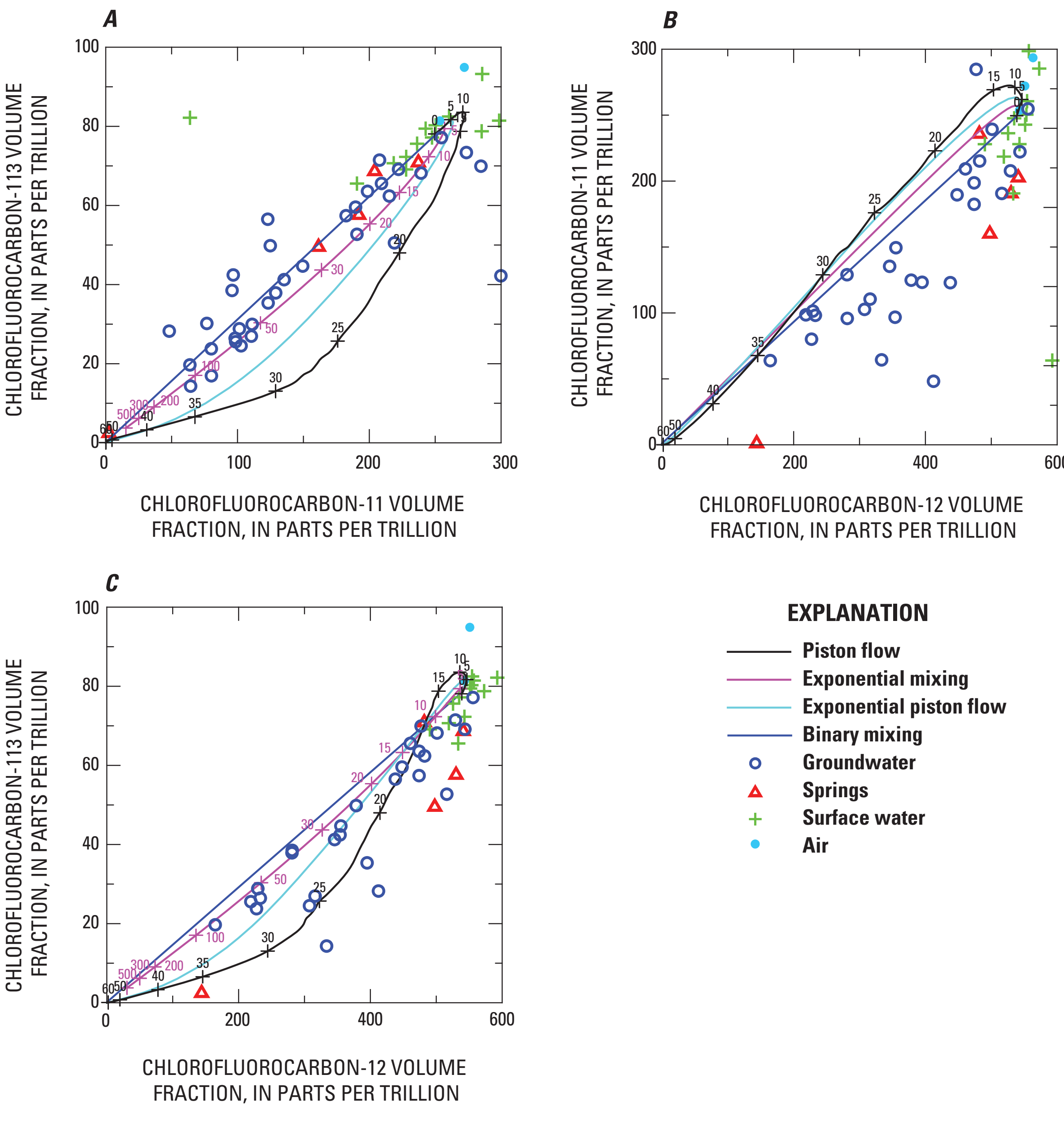


Figure 13-2. Tracer-Tracer plots comparing volume fractions of CFCs in groundwater, water from springs, surface water, and air in the Kabul Basin. The black line represents piston flow, corresponding to CFC volume fractions in parts per trillion (ppt) in North American air. The blue line represents binary mixing of modern water and old, tracer-free water. Model results for the exponential mixing model (magenta) and exponential-piston model (cyan) also are shown (A) CFC-113 versus CFC-11; (B) CFC-11 versus CFC-12; and (C) CFC-113 versus CFC-12. Selected piston flow ages, in years, are given on the piston-flow lines in A–C, and for the exponential model in A and C.

Table 13-2. Summary of dissolved gas composition of selected groundwater samples, estimated excess N_2 from denitrification, estimated recharge temperature and estimated quantity of excess air in the Kabul Basin, Afghanistan.

[m, meters; °C, degrees Celsius; mg/L, milligrams per liter; cc, cubic centimeter; STP/L, Standard Temperature and Pressure per liter]

Site number	Name	Sample date	Time	Estimated recharge altitude (m)	Water temp- era- ture (°C)	N_2 (mg/L)	Ar (mg/L)	O_2 (mg/L)	CO_2 (mg/L)	CH_4 (mg/L)	Estimated excess N_2 from denitri- fication (mg/L)	Calc- ulated recharge temp- erature T (°C)	Calc- ulated excess air cc STP/L
33	Well 033	05/15/07	1000	1,892	nd	16.46	0.5592	0.17	24.52	0.0000	1.0	10.6	1.3
54	Well 054	05/08/07	1000	1,783	nd	13.83	0.4810	1.91	14.73	0.0000	1.0	16.0	0.0
71	Well-71	06/05/07	0940	1,791	20.0	19.28	0.5794	0.14	22.13	0.0000	1.0	15.1	0.4
72	Well-72	06/12/07	0910	1,873	15.2	15.81	0.5425	0.13	23.55	0.0000	1.0	11.5	0.9
73	Well-73	06/17/07	1015	1,593	16.3	17.77	0.5845	0.15	11.48	0.0000	1.5	10.6	1.5
74	Well-74	06/19/07	1140	1,659	15.2	16.07	0.5755	0.32	38.46	0.0000	0.0	11.0	1.6
104	Well 104 Dodumust	05/02/07	1000	2,080	13.5	14.40	0.4886	0.15	22.12	0.0000	1.0	15.0	0.8
129	Well 129	05/19/07	1120	1,807	16.1	16.04	0.5417	0.13	38.59	0.0000	1.0	12.5	1.3
165	Well 165	05/14/07	0930	1,788	15.8	15.70	0.5271	0.14	23.48	0.0000	1.0	13.9	1.3
182	Qala Wazir Well-182	06/02/07	1155	1,933	16.0	17.42	0.5439	0.14	30.01	0.0000	2.5	11.3	1.0
183	Hoot khel Well-183	06/04/07	0905	1,795	18.8	17.99	0.5600	0.14	17.89	0.0083	2.5	11.1	1.3
184	Dehmazang Pampstion Well-184	06/06/07	0920	1,811	15.6	21.12	0.5070	0.11	38.11	0.0000	7.0	15.4	1.2
185	Karte New Well-185	06/16/07	1056	1,810	20.3	15.22	0.4600	0.12	17.17	0.0000	nd [1]	nd [1]	nd [1]
186	Khair Khana Well-186	06/18/07	0940	1,817	18.5	18.28	0.4853	0.12	7.62	0.0000	5.0	16.7	0.6
187	Charkh Aab pum Azizi Hootak Well-187	06/20/07	1030	1,825	15.4	19.95	0.6154	0.14	32.14	0.0000	3.0	7.0	1.4
221	Bagrami Well 221	02/19/07	1120	1,797	13.8	15.78	0.5384	0.33	22.15	0.0000	1.0	12.4	1.0
223	US Embassy Cafe Well	02/22/07	1400	1,798	16.3	16.88	0.5479	0.17	23.61	0.0000	1.5	12.5	1.6

[1] Sample may be degassed.

Table 13-3. Summary of piston-flow and binary mixing model ages of groundwater and spring water based on chlorofluorocarbon data in the Kabul Basin, Afghanistan.

[CFC, chlorofluorocarbon; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, tricllorotrifluoroethane; 1, calculated on rising limb of CFC air curve; 2, calculated on falling limb of CFC air curve; PF, piston-flow model age; Ratio Age, age based on CFC ratio; NP, not possible; nd, not determined; Contam., contaminated--exceeds concentration in water in equilibrium with modern air; Modern, approximately zero age]

Site number	Name	Groundwater region	Sample date	Sample time	CFC-11 PF age (1) years [1]	CFC-11 PF age (2) years [1]	CFC-12 PF age (1) years [1]	CFC-12 PF age (2) years [1]	CFC-113 PF age (1) years [1]	CFC-113 PF age (2) years [1]	CFC-113/ CFC-12 ratio age years [1]	Percent young water in mixture calculated from CFC-113 [1]	CFC-113/ CFC-11 ratio age years [1]	Percent young water in mixture calculated from CFC-113 [1]
							Ground water							
13	Pacha Sahab	Deh Sabz	05-16-2006	1200	31.0	NP	20.5	0.4	23.0	NP	21.4	82.6	16.0	75.9
28	Obchakan Ball	Shomali	05-23-2006	1300	21.9	NP	34.4	NP	18.1	NP	7.9	87.2	11.7	83.5
33	Mir Afghan	Western Front	05-23-2006	1030	32.6	NP	26.9	NP	26.1	NP	25.6	98.3	19.1	56.2
37	Shekhu	Deh Sabz	05-14-2006	1000	33.0	NP	28.7	NP	22.4	NP	18.2	61.8	NP	NP
42	Godar	Shomali	05-28-2006	0810	28.7	NP	24.2	NP	21.4	NP	19.4	82.4	14.4	80.7
47	Dewana	Shomali	05-30-2006	1345	21.4	NP	17.4	NP	18.4	NP	NP	NP	15.9	76.6
54	Alghoai	Deh Sabz	05-21-2006	1145	36.1	NP	34.6	NP	27.6	NP	20.1	39.8	11.1	83.6
59.1	Kata Khel	Eastern Front	05-10-2006	1000	30.9	NP	19.6	NP	19.4	NP	18.9	98.3	NP	NP
65	Khair Khana	Central Kabul	05-25-2006	0930	32.9	NP	31.1	NP	25.4	NP	20.9	58.7	17.4	68.2
71	Well 71	Eastern Front	06-05-2007	0940	32.2	NP	23.7	NP	21.4	NP	19.9	86.4	NP	NP
72	Shakar dara Qalasade-razam	Shomali	06-12-2007	0910	Modern	Contam.	18.7	NP	18.4	NP	NP	NP	NP	NP
73	Well 73	Western Front	06-1720-07	1015	33.7	NP	32.5	NP	25.7	NP	20.7	54.8	17.5	74.1
74	Well 74	Shomali	06-19-2007	1140	23.2	NP	18.0	NP	18.2	NP	NP	NP	NP	NP
104	Dodamast	Western Front	05-13-2006	1100	17.9	2.1	8.9	1.9	16.1	NP	NP	NP	13.6	81.7
105	Karez under Qarga	Paghman/Upper Kabul	05-13-2006	1000	25.0	NP	17.9	NP	19.2	NP	NP	NP	10.9	83.7
107	Dashte Karizak	Paghman/Upper Kabul	05-15-2006	1040	32.9	NP	31.9	NP	25.6	NP	20.6	54.9	17.9	64.9
117	Tangi Saidan	Paghman/Upper Kabul	05-15-2006	1220	20.9	NP	14.4	Contam.	17.4	NP	NP	NP	10.9	83.7
129	Kabul Municipality	Central Kabul	05-24-2006	1255	20.9	NP	Contam.	Contam.	20.1	NP	NP	NP	18.4	61.2
135	Qala-i-Fathulla	Logar	05-17-2006	1050	23.0	NP	17.7	NP	18.2	NP	NP	NP	10.9	83.7
153	Parkhae Sonati	Central Kabul	05-20-2006	1305	37.9	NP	20.9	NP	24.9	NP	NP	NP	NP	NP
165	Qala-i-Baqhalak	Central Kabul	05-22-2006	1000	34.4	NP	Contam.	Contam.	28.7	NP	NP	NP	20.9	45.2
168	Shahrak Police	Central Kabul	05-22-2006	1045	Contam.	Contam.	Contam.	Contam.	21.4	NP	NP	NP	NP	NP
172	Share Now	Central Kabul	05-2220-06	1145	31.9	NP	Contam.	Contam.	24.4	NP	NP	NP	17.4	68.2
182	Qala Wazir	Paghman/Upper Kabul	06-02-2007	1155	20.2	-0.6	16.9	NP	18.9	NP	NP	NP	17.4	74.1
183	Hoot Khel	Central Kabul	06-04-2007	0905	35.7	NP	Modern	NP	25.2	NP	NP	NP	NP	NP

Table 13-3. Summary of piston-flow and binary mixing model ages of groundwater and spring water based on chlorofluorocarbon data in the Kabul Basin, Afghanistan.—Continued

[CFC, chlorofluorocarbon; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, tricllorotrifluoroethane; 1, calculated on rising limb of CFC air curve; 2, calculated on falling limb of CFC air curve; PF, piston-flow model age; Ratio Age, age based on CFC ratio; NP, not possible; nd, not determined; Contam., contaminated--exceeds concentration in water in equilibrium with modern air; Modern, approximately zero age]

Site number	Name	Groundwater region	Sample date	Sample time	CFC-11 PF age (1) years [1]	CFC-11 PF age (2) years [1]	CFC-12 PF age (1) years [1]	CFC-12 PF age (2) years [1]	CFC-113 PF age (1) years [1]	CFC-113 PF age (2) years [1]	CFC-113/ CFC-12 ratio age years [1]	Percent young water in mixture calculated from CFC-113 [1]	CFC-113/ CFC-11 ratio age years [1]	Percent young water in mixture calculated from CFC-113 [1]
							Groundwater—Continued							
184	Dehmazang Pampstion well	Paghman/Upper Kabul	06-06-2007	0920	Contam.	Contam.	Contam.	Contam.	22.7	NP	NP	NP	NP	NP
185	Karte New	Central Kabul	06-16-2007	1056	30.7	NP	25.5	NP	23.0	NP	21.2	83.7	19.0	64.9
186	Khair Khana	Central Kabul	06-18-2007	0940	31.5	NP	30.0	NP	23.5	NP	19.5	61.9	16.5	78.8
187	Charkh Aab Pum Azizi Hootak	Logar	06-20-2007	1030	34.2	NP	25.2	NP	22.7	NP	21.2	85.7	NP	NP
203	Logar	Logar	05-20-2006	1110	23.9	NP	19.4	NP	18.9	NP	18.4	98.0	10.9	83.7
208	Microrayan	Central Kabul	05-20-2006	0930	24.1	NP	14.6	NP	19.9	NP	NP	NP	16.9	71.2
213	Alluddin	Paghman/Upper Kabul	05-15-2006	1305	12.9	11.5	Contam.	Contam.	16.9	NP	NP	NP	NP	NP
219	Khair Khana part 2	Central Kabul	05-24-2006	0935	34.4	NP	31.4	NP	26.4	NP	21.9	59.9	15.1	79.5
221	Bagrami Well 221	Logar	02-19-2007	1120	32.8	NP	27.0	NP	25.8	NP	24.9	92.3	19.5	58.9
223	US Embassy cafe well	Central Kabul	02-22-2007	1400	36.8	NP	26.0	NP	30.8	NP	NP	NP	21.0	49.1
			Average		28.7	4.4	23.5	1.1	22.2	nd	20.0	75.7	15.8	72.1
			Standard Deviaiton		6.4	6.4	6.8	1.1	3.7	nd	3.7	18.3	3.3	11.5
			Median		31.3	2.1	23.9	1.1	22.4	nd	20.6	82.6	16.7	75.0
			Maximum		37.9	11.5	34.6	1.9	30.8	nd	25.6	98.3	21.0	83.7
			Minimum		12.9	-0.6	8.9	0.4	16.1	nd	7.9	39.8	10.9	45.2

Table 13-3. Summary of piston-flow and binary mixing model ages of groundwater and spring water based on chlorofluorocarbon data in the Kabul Basin, Afghanistan.—Continued

[CFC, chlorofluorocarbon; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, trichlorotrifluoroethane; 1, calculated on rising limb of CFC air curve; 2, calculated on falling limb of CFC air curve; PF, piston-flow model age; Ratio Age, age based on CFC ratio; NP, not possible; nd, not determined; Contam., contaminated--exceeds concentration in water in equilibrium with modern air; Modern, approximately zero age]

Site number	Name	Groundwater region	Sample date	Sample time	CFC-11 PF age (1) years [1]	CFC-11 PF age (2) years [1]	CFC-12 PF age (1) years [1]	CFC-12 PF age (2) years [1]	CFC-113 PF age (1) years [1]	CFC-113 PF age (2) years [1]	CFC-113/CFC-12 ratio age years [1]	Percent young water in mixture calculated from CFC-113 [1]	CFC-113/CFC-11 ratio age years [1]	Percent young water in mixture calculated from CFC-113 [1]
						Springs								
66.1	Deh Sabz Khaas Spring	Eastern Front	05-16-2006	1110	27.5	NP	19.6	NP	20.4	NP	20.4	99.9	11.4	83.5
67.1	Istalef Spring	Shomali	05-23-2006	1145	23.7	NP	18.6	NP	19.1	NP	18.4	92.7	13.1	81.2
68.1	Gaza Spring	Shomali	05-21-2006	1000	19.4	NP	17.1	NP	17.1	NP	NP	NP	14.6	80.9
101	Chandal Bai Spring	Western Front	05-13-2006	1130	Contam.	Contam.	Contam.	Contam.	14.6	4.6	NP	NP	NP	NP
180	Khaja Safa Spring	Central Kabul	06-17-2006	0945	56.1	NP	46.0	NP	45.6	NP	0.0	NP	0.0	NP
181	Chara Sib Spring	Logar	06-17-2006	1135	22.5	NP	15.5	NP	17.6	NP	NP	NP	NP	NP
			Average		29.8	nd	23.4	nd	22.4	4.6	12.9	96.3	9.8	81.9
			Standard Deviaiton		15.0	nd	12.7	nd	11.5	nd	11.2	5.1	6.6	1.4
			Median		23.7	nd	18.6	nd	18.3	4.6	18.4	96.3	12.2	81.2
			Maximum		56.1	nd	46.0	nd	45.6	4.6	20.4	99.9	14.6	83.5
			Minimum		19.4	nd	15.5	nd	14.6	4.6	0.0	92.7	0.0	80.9

[1] Calculated using altitude, recharge temperatures and excess air from Table 13-2.

Table 13-4. Summary of average ages, percentages of young water, and percentages of modern water, based on concentrations of chlorofluorocarbons and tritium in groundwater and water from springs by subbasin and source area in the Kabul Basin, Afghanistan.

[Location of basins shown on figure 6. Average CFC values do not include water from Karez 105 (site number 105). CFC, chlorofluorocarbon; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, trichlorotrifluoroethane; TU, Tritium Unit]

Groundwater subbasin or area	Average piston flow ages in years[1]			Average ratio-based ages and percent young water[1]				Average percent modern[2]			Tritium in TU
	CFC-11	CFC-12	CFC-113	Age from CFC-113/CFC-12 ratio	Percent young water from CFC-113	Age from CFC-113/CFC-11 ratio	Percent young water from CFC-113	CFC-11	CFC-12	CFC-113	
Eastern Front Source Area	30	21	20	20	95	11	84	55	81	67	6.1
Western Front Source Area	28	23	21	23	77	17	71	85	86	68	12.0
Shomali	23	21	19	15	87	14	81	86	88	81	13.5
Deh Sabz	33	28	24	20	61	16	80	38	52	40	7.6
Central Kabul	34	28	26	17	66	18	65	63	394	39	8.4
Paghman and Upper Kabul	22	20	20	21	55	14	77	89	162	72	12.1
Logar	27	21	21	22	92	14	75	65	79	67	10.4

[1] Averages of all samples that could be dated using CFCs, excluding CFC contaminated samples.

[2] Average of all samples that could be dated using CFCs, including CFC contaminated samples.

Although the average CFC-based ages are similar throughout the Kabul Basin, there are apparently some age differences on relatively local scales within the Kabul Basin groundwaters. Many of the CFC-11 apparent ages are older than those based on CFC-12 and CFC-113, particularly in parts of the Central Kabul, Deh Sabz, and Shomali regions (figs. 13-3–13-5). The relatively older CFC-11-based ages are likely the result of microbial degradation of CFC-11, which causes an old bias in apparent age. There is a greater tendency for elevated CFC-12, and to a lesser extent, CFC-11, amounts (noted “Contaminated”, meaning volume fractions exceed modern air-water equilibrium values) in the Central Kabul and Paghman and Upper Kabul regions (figs. 13-3, 13-4). The elevated CFC-11 and CFC-12 volume fractions likely reflect localized anthropogenic sources of CFCs in the more urban areas. Some of the CFC-113 apparent ages are younger than those based on CFC-12 in parts of the Shomali, Deh Sabz, and Central Kabul regions. Localized anthropogenic sources of CFC-113 and (or) binary mixing of young and old water would lead to a young bias in CFC-113 apparent ages (fig. 13-5). However, none of the groundwater samples are contaminated (exceed modern air-water equilibrium values) with CFC-113, yet modern air samples from the region are substantially elevated in CFC-113. Apparently, the elevated CFC-113 volume fractions in modern air are a recent phenomenon in the Kabul Basin.

Age Gradients in Groundwater

Well depth and water-level data were available for 25 of the 35 wells sampled for CFCs. However, there was no information on length of well casing or depth of the open interval for any of the wells. Information on variations in groundwater age with depth below the water table was obtained by plotting the CFC apparent (piston-flow) ages as a function of the mid-depth of the saturated interval between the water table and total depth of the well (fig. 13-6). All three tracers show increasing age with depth below the water table. The depth gradients ranged from 1.4 to 2.8 m/year. Assuming a saturated porosity of 25 percent, the age gradients imply a vertical component of recharge of 0.35 to 0.7 m/year. Because most of the groundwater recharge is thought to be from infiltration of water beneath streams and rivers, this range of estimated recharge rate applies primarily to infiltration of surface water beneath irrigation canals, streams, and rivers, rather than spatially across the basin.

It is interesting that the depth-age gradients of figure 13-6 do not appear to extrapolate to zero age at the water table, implying apparent ages of 10 to 15 years at the water table. As pointed out above, only a few samples can be interpreted with dual ages that would yield very young ages. Most of the water samples appear to have piston-flow ages that precede the turnover in atmospheric CFC air curves (early- to mid-1990s). Further, it is unlikely that infiltration from rivers and streams passes through deep unsaturated zones that might exchange CFCs with old resident air. It is more likely that the trends in depth-age gradients turn asymptotically, approaching zero age at the water table; but because of the relatively large open intervals of the wells, insufficient discrete shallow water-table samples were obtained that could demonstrate this trend.

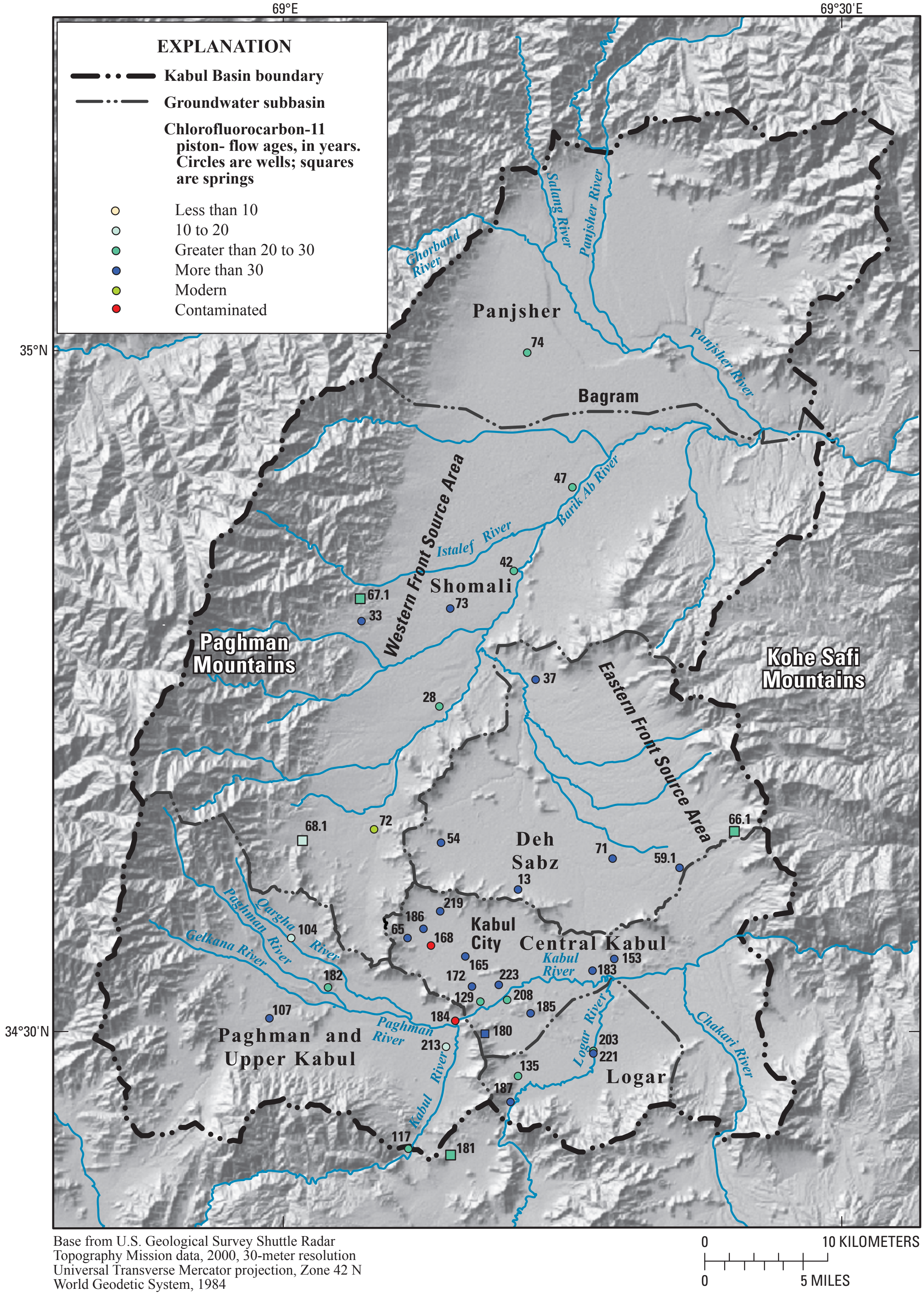
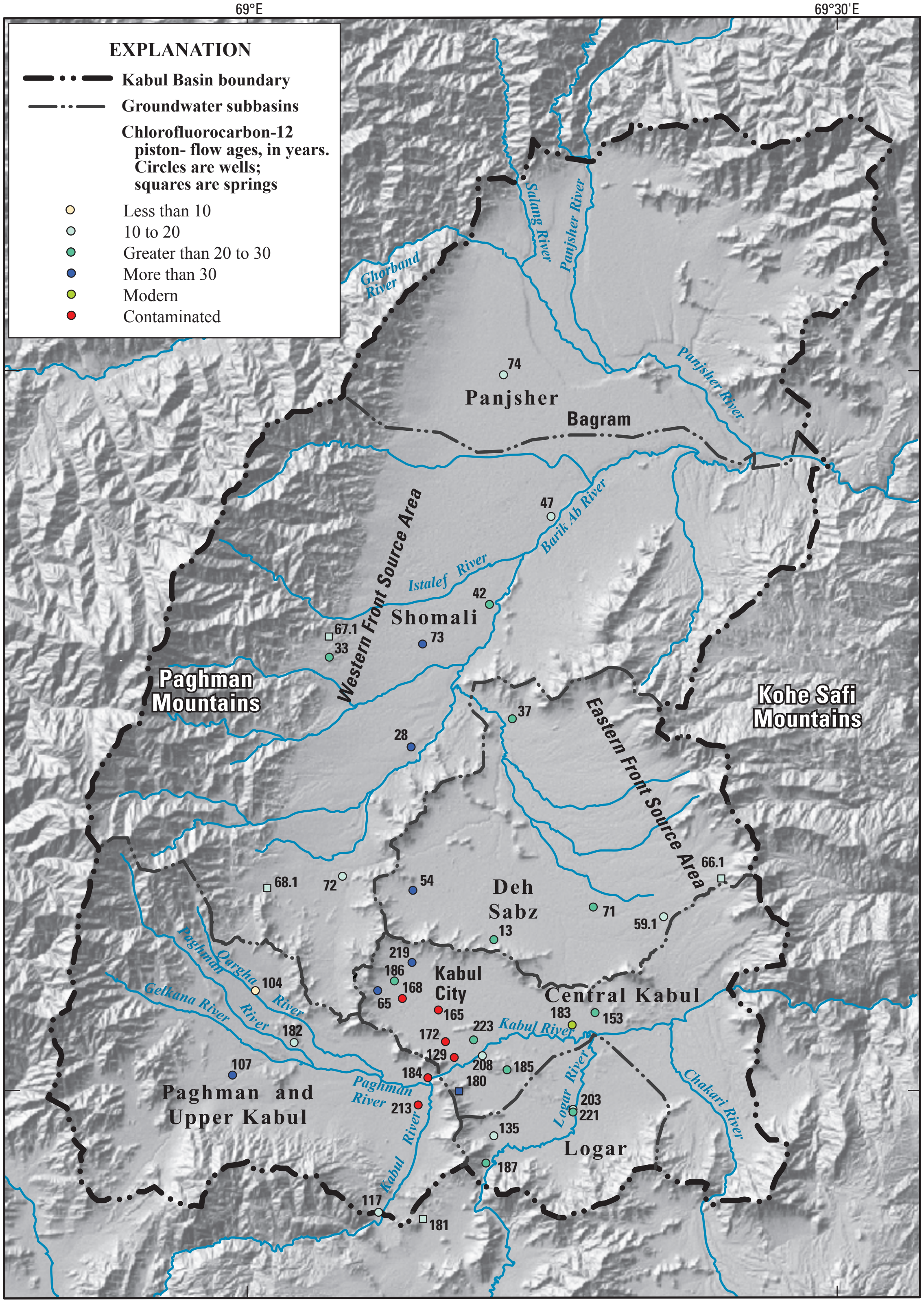


Figure 13-3. CFC-11 piston-flow ages in the Kabul Basin, Afghanistan.



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 13-4. CFC-12 piston-flow ages in the Kabul Basin, Afghanistan.

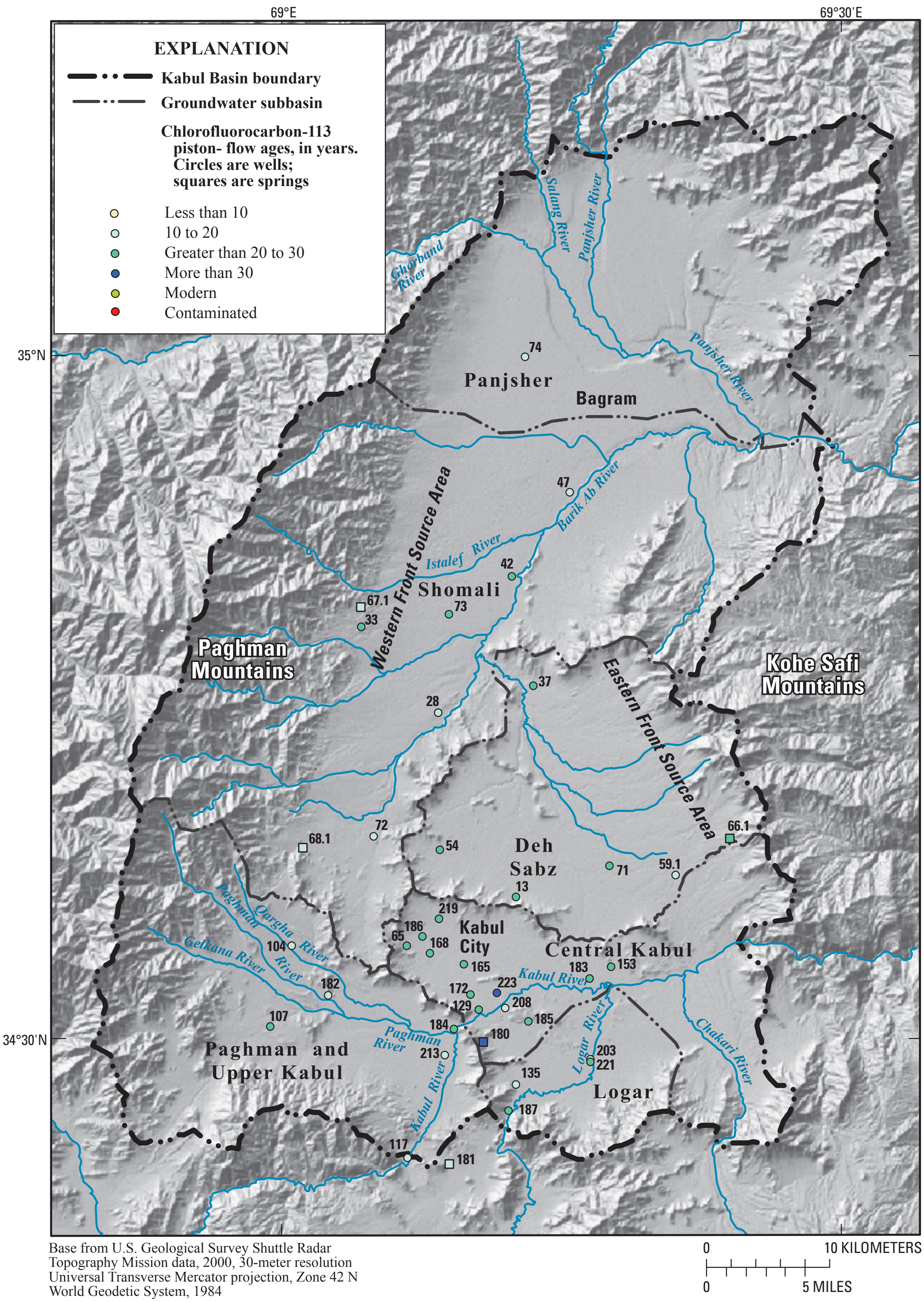


Figure 13-5. CFC-113 piston-flow ages in the Kabul Basin, Afghanistan.

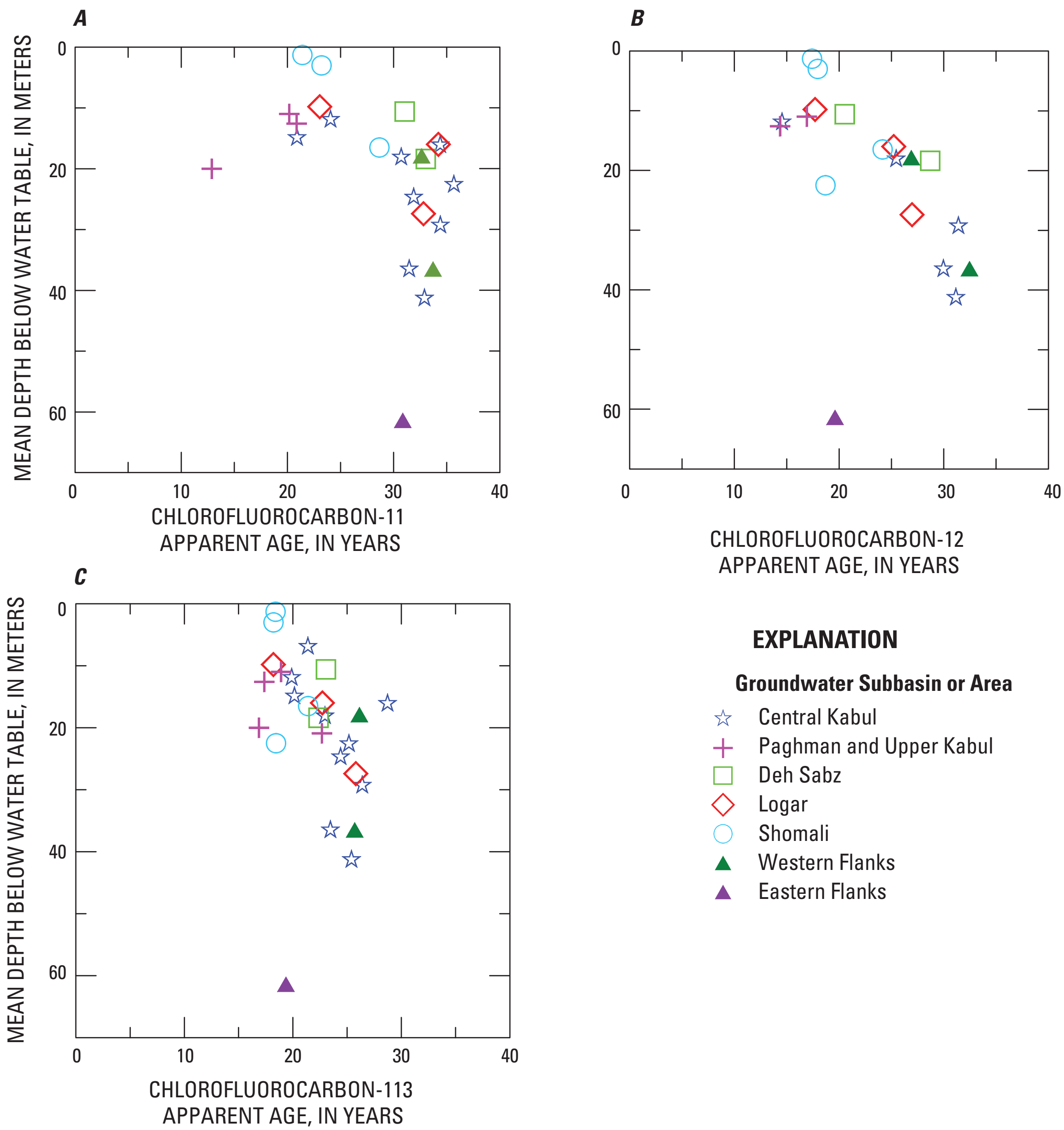


Figure 13-6. Apparent (piston-flow) ages as a function of depth below the water table. Symbols are at the mid-depth of the saturated interval intercepted by the well. The ages were based on (A) CFC-11, (B) CFC-12, and (C) CFC-113. (This figure is the same as figure 25).

Although water would infiltrate nearly vertically beneath the rivers, the water is expected to move laterally away from the rivers to areas of considerably less recharge, resulting in older age near the water table at distances further from rivers and other sources of surface-water infiltration. As a result, the observed depth-age gradients provide only a rough estimate of recharge rate that can be applied only near rivers and streams. Future modeling efforts may be able to utilize the depth-age information to derive more reliable estimates of recharge rates from rivers and streams in the Kabul Basin.

Comparison of CFC and Tritium Data

The CFC transient tracer data are examined in relation to tritium data in figure 13-7. Because of the greatly different shape in input function over time relative to that of CFCs, tritium is a particularly useful environmental tracer in combination with CFC data in interpreting mixing models and groundwater age.

Three categories of samples are apparent in examining tritium in relation to CFCs (fig. 13-7). The first group of samples plot close to the piston-flow line, including both groundwater and surface-water samples. These samples are thought to be mostly unmixed and likely have valid apparent (piston-flow) ages. A second group of samples plot below the piston-flow-model line, and these samples may be dilutions of post-bomb era waters (including modern water) with older water low in tracer concentration. The third group of samples plots above the piston-flow line and includes surface water, groundwater, and water from springs. Some of these samples could be interpreted as exponential or exponential-piston flow mixtures with mean ages of 5 to nearly 40 years, having somewhat older ages than the apparent (piston-flow) ages. Other samples from this group plot above the exponential and exponential-piston-flow model lines. These samples may represent a group of somewhat older waters recharged in approximately the late 1970s to early 1980s, during a time of elevated CFC concentrations in the Kabul Basin environment. Selected recharge years, marked (in black) along the piston-flow model lines in figure 13-6, can be used to infer tritium-based ages for these samples.

Another possibility to explain the elevated tritium in some samples is to consider a groundwater lag that affects the tritium concentration in groundwater discharge to rivers, because of the mean residence time of groundwater (Michel, 1992). A groundwater lag could shift the bomb-era tritiated water to somewhat younger ages, but probably not the 25–30 years implied by the samples with elevated tritium. Another alternative hypothesis is that some of the Kabul Basin waters were slightly contaminated with tritium in the past 20 years or so, but there is no evidence for this possibility.

Unfortunately, there are not sufficient data to resolve the multiple hypotheses for the origin of the waters plotting above the model lines in figure 13-7. However, data from one spring (site 180) has very low CFC-11 and CFC-113 but elevated tritium and CFC-12. The CFC-11, CFC-113, and tritium data are concordant suggesting that this sample has a mean age from the late 1950s to early 1960s, but it also contains a small fraction of water contaminated in CFC-12 (fig. 13-7). This observation supports the hypothesis that the waters plotting above the model lines have elevated CFC concentrations, at least with regard to CFC-12.

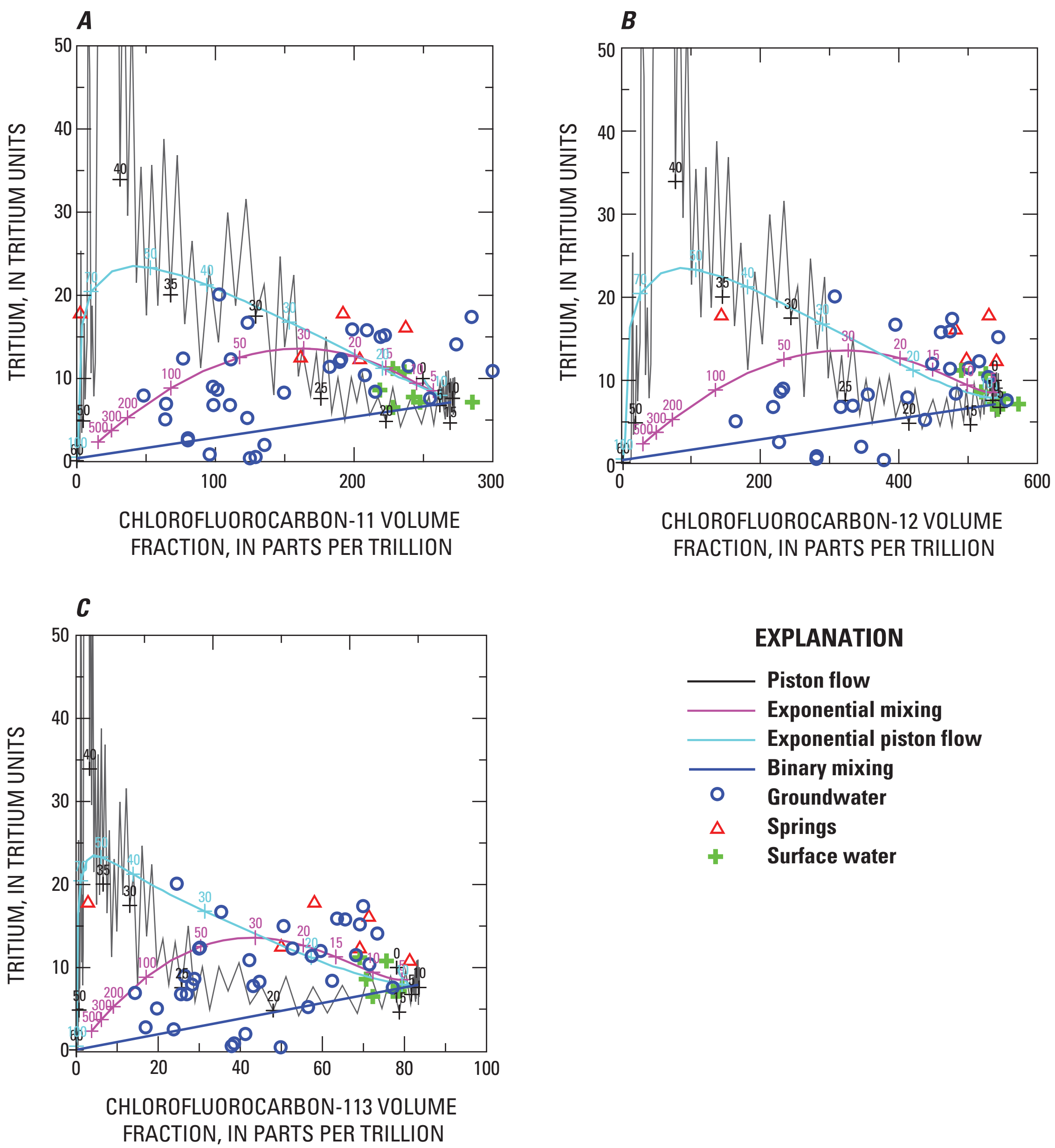


Figure 13-7. Tracer-Tracer plots comparing tritium and CFC volume fractions in groundwater, water from springs, and surface water in the Kabul Basin. The black line represents piston flow, corresponding to CFC volume fractions in parts per trillion (ppt) in North American air and tritium in Kabul Basin precipitation decayed to the sampling year 2006. The blue line represents binary mixing of modern water and old, tracer-free water. Model results for the exponential mixing model (magenta) and exponential-piston model (cyan) also are shown (A) Tritium versus CFC-11; (B) Tritium versus CFC-12; and (C) Tritium versus CFC-113. Selected mean ages in years are given at plus signs along the piston-flow, exponential mixing and exponential-piston-flow lines.

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Appendix 14. Simulation of the Groundwater-Flow System

Contents

Figures

Tables

Appendix 14. Simulation of the Groundwater-Flow System

The various components of the groundwater flow system were estimated on the basis of results of this study, information obtained from other investigations, and groundwater-flow simulations. Mean monthly fluxes, inflows and outflows, in the Kabul Basin aquifer system are presented in table 8. The hydrologic components of the Kabul Basin were summarized by northern subbasins and southern subbasins that can be considered hydrologically separate sub-regional flow systems. The fluxes were estimated on the basis of calculated base flows into and out of the Kabul Basin, actual evapotranspiration (AET), chemical and isotopic information, and knowledge of the basin hydrology gained in this investigation. The mean monthly fluxes were estimated using information from different periods of time (historical and recent). The differences between mean inflows and outflows presented in table 8 were not balanced on an annual basis and, at the monthly scale, the differences include errors from multiple or undifferentiated components of the flow system. Changes in groundwater storage may account for a large portion of the monthly difference in fluxes in nongrowing seasons and an undefined portion of the differences during the growing season. It is not known to what magnitude of estimated recharge, evapotranspiration (considered as a component of net recharge), irrigation leakage, or a combination of these and other factors were represented in the monthly differences during the growing season. The fluxes are therefore considered general approximations of the components of the regional groundwater flow system. Because of the uncertainties in the flux estimations, and numerical simulation of the various components of the flow system discussed in the following sections, the groundwater-flow simulation used mean annual inflow rates with a steady-state model. Because of the limitations of using historical streamflow data with recent water-level data, and the unknown magnitude of irrigation leakages, no attempt was made to simulate transient monthly fluxes as represented in table 8.

Model Limitations

The groundwater-flow model of the Kabul Basin provides a regional-scale simulation of groundwater flow and water balance but is not intended for site-specific analysis. Ground-water-flow models are a numerical representation of the physical flow system and require simplifications and assumptions. Limitations are inherent in the practical application of ground-water-flow models, and the assumptions and simplifications incorporated in a model depend on the intended use of that model. For example, the Kabul Basin model does not simulate unsaturated-zone flow processes (groundwater flow above the water table), or the direct, or overland, component of streamflow; instead, the model simulates the base-flow component of streamflow, or ground-water discharge. Evapotranspiration also is not specifically simulated but is accounted for within a net (or effective) recharge. Other model simplifications include the parameterization of hydrogeologic properties and characteristics into homogenous units and the assignment of these parameters to groups of cells with areas of 400 m by 400 m and thicknesses that depend on the model layer. Simplification also includes the temporal grouping of recharge, streamflow, and groundwater-flow characteristics into a median annual period.

Some components of the flow system could only be approximated given the limitations of this investigation, for example, the groundwater inflows at the mountain front as represented by general-head boundaries (GBH). Although final model parameter values and sensitivities are presented in table 14-1 the simulation model is not considered to be fully calibrated because of the limited input data. Some of these limitations are reflected by large 95-percent confidence intervals for some parameters (table 14-1). However, the simulation supports the conceptual understanding of the groundwater-flow system. The simulation results can be considered to provide a general representation of probable groundwater-flow conditions but are not intended for use at the local scale.

Table 14-1. Model parameters and sensitivity in the conceptual groundwater flow system for the Kabul Basin, Afghanistan.

[E, exponential; C.I., confidence interval, m/d, meters per day; n.a., dimensionless factor; –, CI is not meaningful or is more than 5 orders of magnitude from the parameter value]

Parameter name	Sensitivity (dimensionless)	Sensitivity rank	Upper 95 percent C.I.	Final value	Lower 95 percent C.I.	Units	Parameter description, recharge zone, or hydrogeologic material group
Rech1	2.4E-01	14	7.E-02	1.E-03	2.E-05	m/d	Infiltration recharge rate, Panjsher subbasin
Rech2	7.1E-01	9	9.E-02	1.E-03	2.E-05	m/d	Infiltration recharge rate, western Shomali subbasin
Rech3	1.2E-01	16	1.E+00	1.E-03	1.E-06	m/d	Infiltration recharge rate, southern Central Kabul and Logar subbasins
Rech4	6.8E+00	2	1.E-03	7.E-04	3.E-04	m/d	Areal recharge rate, entire Kabul Basin
STR1	7.1E+00	1	5.E+00	3.E+00	2.E+00	n.a.	Streambed hydraulic conductance factor,
K1	6.6E-01	10	7.E+02	5.E+01	4.E+00	m/d	Horizontal hydraulic conductivity, fan alluvium and colluvium
K1v	7.2E-04	23	–	5.E+00	0.E+00	m/d	Vertical hydraulic conductivity, fan alluvium and colluvium
K2	7.6E-02	18	5.E+06	1.E+02	2.E-03	m/d	Horizontal hydraulic conductivity, river channel sediments
K2v	1.5E-04	24	–	1.E+01	–	m/d	Vertical hydraulic conductivity, river channel sediments
K3	4.5E+00	3	9.E+01	2.E+01	4.E+00	m/d	Horizontal hydraulic conductivity, loess
K3v	8.7E-03	21	–	2.E+00	–	m/d	Vertical hydraulic conductivity, loess
K4	3.0E-01	13	7.E+02	2.E+00	6.E-03	m/d	Horizontal hydraulic conductivity, conglomerates and sandstone
K4v	2.4E-02	20	–	2.E-01	–	m/d	Vertical hydraulic conductivity, conglomerates and sandstone
K5	2.1E+00	5	2.E+02	2.E+00	2.E-02	m/d	Horizontal hydraulic conductivity, upper Neogene
K5v	7.5E-01	8	–	2.E-01	–	m/d	Vertical hydraulic conductivity, upper Neogene
K6	1.8E+00	6	1.E+02	5.E+00	2.E-01	m/d	Horizontal hydraulic conductivity, lower Neogene
K6v	8.8E-02	17	–	5.E-01	–	m/d	Vertical hydraulic conductivity, lower Neogene
K7	1.5E-01	15	–	1.E-01	–	m/d	Horizontal hydraulic conductivity, sedimentary rocks
K7v	8.3E-04	22	–	1.E-01	–	m/d	Vertical hydraulic conductivity, sedimentary rocks
K8	3.6E+00	4	3.E-02	1.E-02	4.E-03	m/d	Horizontal hydraulic conductivity, metamorphic and igneous rocks
K8v	5.1E-01	11	1.E+00	1.E-02	8.E-05	m/d	Vertical hydraulic conductivity, metamorphic and igneous rocks
GHB1	3.5E-01	12	5.E+03	1.E-02	–	n.a.	General-head boundary hydraulic conductance, Paghman Mountains
GHB2	4.0E-02	19	–	1.E-02	–	n.a.	General-head boundary hydraulic conductance, southern mountains
GHB3	1.6E+00	7	2.E+01	1.E-01	4.E-04	n.a.	General-head boundary hydraulic conductance, Kofi Safi Mountains

Direct Recharge and Evaporation

Average annual precipitation is low in the Kabul Valley; between 1959 and 1971 it was 329 mm/yr (Böckh, 1971). Evaporation rates are high, approximately 1,600 mm/yr, relative to annual total precipitation; therefore, direct groundwater recharge by precipitation in the Kabul Valley is generally near zero on an annual basis. Houben and Tunnermeier (2005) estimated annual recharge to be zero for a few years during the early 2000s. Mean monthly precipitation (table 1) historically was highest between February and 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/mo during the growing season (April to September). Therefore, recharge by direct infiltration of precipitation generally occurs only from late fall to early spring. Recharge was applied on a regional aerial basis in the conceptual model using the Recharge package (Harbaugh and others, 2000) where a net recharge is applied consisting of the monthly mean rate of precipitation minus the evaporation rate. Where the valley floor is covered by loess (fig. 2), because of the clay content of the loess (appendix 7), infiltration rates in the loess can be expected to be lower and evaporation rates higher than the quaternary sediments. A BGR investigation in Kabul (Niard, 2007) calculated a maximum potential infiltration rate of 39.1 mm/m^2 for sandy soils and 20.5 mm/m^2 (or 75 percent of maximum rates) for direct precipitation on loess; therefore, simulated recharge was reduced by 75 percent in loess-covered areas.

Monthly recharge by direct infiltration of precipitation was assumed to be zero for the months where precipitation was low and evaporation was high, June through October. For December through April, the monthly direct recharge rate varies and was estimated to range up to about 3^{-3} m/d during spring runoff (table 14-1). During the nongrowing season, recharge by direct infiltration of precipitation on the aquifers in the subbasins, on the basis of precipitation and evaporation (Böckh, 1971; Houben and Tunnermeier, 2005), may be approximately 30 mm/yr. A mean annual net (recharge minus ET) direct recharge rate was estimated by analysis of base flows and conceptual groundwater-flow simulation to be approximately 0.7^{-3} m/d. Recharge was further distributed to simulate irrigation leakage; in agricultural areas, a recharge rate about two times the areal rate was applied.

Stream Inflows, Leakage, and Outflows

Leakage from the major rivers flowing through the basin has been identified as a source of recharge to the Kabul Valley (Böckh, 1971). The major river channels are generally comprised of coarse-grained sands and gravels (fig. 2) and incise the fine-grained surficial sediments (loess) where present. The river channels represent areas with considerable potential for infiltration (Niard, 2007). Rivers and streams in the Kabul Basin were simulated with the MODFLOW Stream package (Prudic and others, 2004) in the model layer 1 subbasin areas (figs. 1 and 8). Inflows were simulated at four rivers that flow into the northern subbasins and four rivers that flow into the southern subbasins (figs. 1 and 4). Outflows at the Panjsher River at Shukhi, for the northern subbasins, and the Kabul River at Tang-i-Gharu, for the southern subbasins, capture all streamflow out of the Kabul Basin. The groundwater flow model does not simulate streamflow, but rather the component of streamflow comprised of groundwater discharge. Therefore, a mean monthly base-flow rate calculated using streamflow partitioning methods (Rutledge, 1998) was used to represent river inflows to the model area (table 14-1). Base flows are generally slightly less than mean streamflows for a similar period. Use of base flows in the groundwater flow model reflects the fact that during periods of high flows only a relatively small fraction of the streamflow might infiltrate to the aquifer system.

The perennial streams that flow into the basin from upland areas (fig. 4) contribute inflows to the model and were simulated with the Stream package in model layer 1 in subbasin areas (figs. 1 and 8). Streams were not simulated in the upland areas of the model represented by model layer 2. Inflows from upland areas of the Paghman Mountains were calculated assuming that inflows occur at a rate equal to that of similar upland drainages elsewhere in the study area, and were simulated where tributary streams cross into model layer 1. Mean annual base flow (0.017 m^3/s/km^2) calculated at the Shatul River drainage, a 202-km^2 area with no glaciers, was believed to be representative of upland discharges adjacent to the study area and was used to approximate inflows at perennial upland tributaries to the Barik Ab stream, at the Western Front Source Area (fig. 1), and the Paghman and Upper Kabul Rivers, representing areas of about 321 km^2 and 95 km^2, respectively. Streams on the east side of the Kabul Basin (Deh Sabz subbasin) are ephemeral and were simulated without a specified headwater inflow.

Streamflow losses at measured at gaged sections of several rivers in the Kabul Valley are presented by Böckh (1971) and indicate very permeable streambeds with the potential for high rates of leakage. Although streambed hydraulic conductivity is probably on the order of 10s of meters per day, streambed hydraulic conductivity was simulated at 2 m/d to prevent numerical oscillation. Streams were simulated with a riverbed width of 10 m for larger rivers to 1 m for smaller streams. Stream stage was assumed to be 1 m below the DEM surface with a 1 m thick riverbed.

Hillside Groundwater Inflows

Monthly mean base flows discussed above can be considered to be primarily composed of groundwater discharge with the exception of snowmelt periods. The base flows to perennial streams, because they are not in glacially covered areas, represent groundwater discharge that was channeled in the upland drainage area and expressed as streamflow. Precipitation on the hillsides or mountains also seeps through the hillsides or mountains and enters the subbasin valley aquifers laterally as groundwater flow at the valley walls. Isotopic sampling indicates that this is likely a source of recharge to the Western Front Source Area and Eastern Front Source Area (fig. 1). Where high-elevation upland areas are adjacent to the subbasins, groundwater inflows are likely to occur. The presence of winter snowpack would likely contribute to recharge to the hillside bedrock aquifers that may provide delayed groundwater inflows to the subbasins during periods with less recharge.

The drainage divide at the eastern flank of the Kabul Basin is immediately adjacent to the Deh Sabz subbasins and very little upland area slopes towards the basin from the east. However, some groundwater likely flows into the Deh Sabz from the drainage area east of the Deh Sabz. Support for this include perennial springs that originate at the base of the hillside (Akbari and others, 2007); isotopic sample results indicate that the groundwater at the Eastern Front Source Area is distinguishable from groundwater in the other areas of the Deh Sabz subbasin; and heads at wells 4, 7, and 59.1 (Akbari and others, 2007) are approximately 100 to 200 m greater than the elevation of the nearest perennial river, the Kabul River. The mountain ridge east of Deh Sabz is composed of sandstones and limestones (Bohannon and Turner, 2007) and is likely to have a greater porosity and water storage and transmitting capacity than bedrock elsewhere in the study area. For example, isotopic analysis (fig. 25) indicates a regional age and depth relation to groundwater that results from a combination of direct precipitation recharge and irrigation leakage. An outlier on figure 25 from a sample collected from the eastern area of the Deh Sabz subbasin does not fit the regional trend in that the groundwater is much younger than expected at depth. This well is in an area where no irrigation is present and likely receives the least amount of precipitation recharge in the Kabul Basin. This sample indicates that hillside groundwater inflows occur at the Eastern Front Source Area adjacent to the Kohe Safi Mountains.

Groundwater inflows were simulated in model layer 2 (fig. 8) using the MODFLOW-2000 general-head boundary (GHB) package (Harbaugh and others, 2000) at the base of hillsides that form the perimeters of Kabul Basin (equivalent to the lateral extent of model layer 1). Heads in the Quaternary aquifer at the base of such hillsides varied from 10 to about 50 m below the land surface. A head equal to the midpoint of model layer 1 thickness was used in the general-head boundary. The hydraulic conductance, a dimensionless multiplication factor used in the GHB package, was 0.01 at igneous and metamorphic hillsides such as the Paghman Mountains and 0.1 at sedimentary rocks such as the Kohe Safi Mountains. Without additional inflows, particularly at the Eastern Front Source Area of the Deh Sabz subbasin, simulated groundwater levels were generally too low at the valley walls. However, this inflow represents a small fraction (about one tenth) of the total simulated flux in the Kabul Basin.

Domestic Water Use

Groundwater withdrawals for domestic purposes were approximated by applying a per-capita water-use rate times the estimated population by kilometer-scale geographic information system (GIS) grid cells (fig. 26). Withdrawals were simulated in model layer 1, using the WEL package (Harbaugh and others, 2000), at grid cells with a population greater than 10. A per-capita water-use rate of 30 L/d was used in urban areas. A lower per-capita rate was initially considered for rural areas; however, rural water use likely includes additional water uses for gardens and livestock and may be comparable to urban-use rates. A per-capita water-use rate of 20 L/d was used in rural areas.

Future water uses were simulated by increasing the simulated current water use by a factor of six following present population patterns (fig. 26). Future water uses were also examined by simulating withdrawals in the lower Neogene aquifer at major population centers to represent hypothetical municipal supply centers.

Agricultural Water Use

Agriculture in the Kabul Valley relies primarily on irrigation and less so on rainfall early in the growing season of April through September. Irrigation water is generally obtained from nearby streams and, to a lesser degree, is also supplied by karezes, springs, and wells. There are no records of the amount of water used in the Kabul Basin or how it is distributed; however, the efficiency of water applied on crops has been reported to be about 25 to 30 percent because of leakage and evaporation (Banks and Soldal, 2002). As discussed previously, agricultural water use can be inferred from analysis of land cover in satellite imagery. Larger croplands represent areas where streamflow has been diverted for irrigation and may also infiltrate to the subsurface. Senay and others (2007) estimated rates of actual ET for the three main agricultural areas in the Kabul Basin that are termed in this report: (1) the *northern area*, in the Panjsher River and Bagram area; (2) the *western area*, at the flank of the Paghman Mountains in the flood plain of the Barik Ab River, south of the confluence with the Panjsher River; and (3) the *southern area* in the flood pain of the Paghman, Kabul, and Logar Rivers.

The majority of the irrigated water is from streamflow diversion to irrigation canals during periods of available streamflow. Later in the summer months, particularly August and September, little or no flow is available for irrigation in the rivers in the southern half of the study area (figs. 13 and

14) including the perennial streams originating in the Paghman Mountains. Pumped groundwater is not likely to be a large contribution to the total irrigation because of the expense of fuel and the infrastructure needed to supply large amounts of water. Where present, karezes and springs provide water for irrigation; however, these sources are also likely to contribute a lesser amount of water because springs and karezes are not numerous and groundwater declines in recent years may have reduced their productivity (Banks and Soldal, 2002). During the summer months, the rivers in the Kabul area are generally depleted by intense irrigation (Böckh, 1971).

The water used for agriculture is diverted from streams flowing into, or through, the Kabul Basin and the transpiration component (AET, fig. 7) represents a loss of water from the system. Because irrigation efficiencies are expected to be large (50 percent or more), the irrigation areas and the AET water-use rates provide locations and relative magnitudes where recharge occurs, in the form of irrigation leakage, to the groundwater system. The magnitude of irrigation-derived recharge is not known and could not be differentiated from areal recharge, for simulation in the groundwater flow model, with the information available. Recharge due to irrigation leakage is likely equal to or greater than areal recharge and was simulated at a mean annual rate of 1.2^{-3} m/d, or nearly twice the areal recharge rate (0.7^{-3} m/d).

Neogene Aquifer

The expected growth in Kabul will require additional water for domestic and agricultural uses. A potential source of future water supply for Kabul may be the Neogene aquifer, which underlies the Pleistocene and recent aquifers that are presently in use (fig. 8). The hydraulic characteristics and quality of water in the Neogene aquifer are not well known because of the difficulties and expense of drilling deep wells in Kabul. However the Soviet "Passport" investigations of the late 1970s (Japan International Corporation Agency, 2007b) and recent Japan International Corporation Agency (2007a, b) investigations indicate that the thickness of the aquifer is more than 600 m in some subbasins, which may provide considerable storage. The Neogene generally consists of fine-grained, compact sediments with corresponding low permeabilities and is differentiated by Japan International Corporation Agency (2007b) into an upper and lower aquifer. The upper Neogene aquifer extends to about 400 to 500 m below land surface and consists of a mudstone, a clay, and clay with gravel. The lower Neogene may extend up to 1,000 m or greater (Homilius, 1969), in some localized areas near the centers of some subbasins, and consists of gravel and sand with mudstone. However, borehole geophysical logs contained in Passport reports and recently collected by Japan International Corporation Agency (2007b) indicate that a coarse-grained basal conglomerate is present in some locations in the lower Neogene formation. Such coarse-grained lenses may not be laterally continuous; however, discontinuous lenses may permit water to be extracted from the surrounding low permeability aquifer. The sustainability of large withdrawals from the Neogene aquifer are not known but can be assessed with hypothetical simulations.

To assess the source of water to the Neogene aquifer and assess the potential impact of large withdrawals on the water resources of Kabul, several hypothetical supply wells were simulated at major population centers in the subbasins. This analysis does not assess the likelihood of suitable locations for withdrawals in the Neogene aquifer or the quality of water withdrawn. The withdrawals were assessed with respect to impact on water levels in the overlying aquifer, which would affect existing water uses, and the source of water withdrawn, which would indicate the potential sustainability of the withdrawal. The simulated well does not imply that the location is a favorable location for groundwater extraction. The implications of the impact of multiple withdrawals in each basin can be qualitatively inferred from the results presented. Withdrawal wells were simulated in the upper 100 m of model layer 3 to represent withdrawals from the upper Neogene aquifer.

Withdrawals in the Neogene aquifer near the flank of the Paghman Mountains may be more successful than withdrawals from other areas of the Kabul Basin because of recharge from the upland areas and increased storage in the underlying bedrock. The bedrock in this area is likely to be more highly fractured than elsewhere in the study area because of a greater density of faults in this area (Ruleman and others, 2007). Water stored in the underlying bedrock aquifer also may be recharged from precipitation on the mountains through fracture zones. However, withdrawals in this area may reduce flows to streams or karezes in the area. Withdrawals in the Dez Sabz subbasin, and near the eastern mountain flanks in the Shomali Plain, may be sustainable depending on groundwater inflows from the Kohe Safi Mountains.

Model Calibration and Parameter Sensitivity

The steady-state model was calibrated to observations of groundwater and surface-water levels and groundwater discharge to streams following the methods of Hill (1998) and Hill and others (2000). The model was calibrated in a regional manner, where model characteristics were adjusted by parameter zones, which form relatively large geologic or hydrologically consistent areas. For example, the hydraulic conductivity of each geologic unit was kept consistent within that unit and changes were made to the unit as a whole. Geohydrologic units used were eight broad classifications consisting of four unconsolidated sediment units (Quaternary sediments, loess, river-channel sediments, and upper and lower Neogene sediments), and two general bedrock units; metamorphic and igneous, as one unit, and sedimentary rock as a second unit (appendix 6). Parameters used in the model include the hydraulic characteristics used to define the geohydrologic units and other features such as recharge or streambed conductivity. Although a better model fit between observed and simulated data could likely be obtained by locally adjusting cells within parameter zones, such modifications made without a conceptual basis do not improve the understanding of hydrologic processes and may not result in a realistic model. Instead, the goal of the calibration process is to help understand regional hydrogeologic processes as opposed to matching observations. In the parameter estimation process used in this study, not all parameters were estimated in one simulation. Selected parameters were estimated while some were held fixed. The procedure was repeated, with other parameters estimated or held fixed, until optimal parameter values, with reasonable values, were identified for all parameters. The sensitivity of the parameters was evaluated simultaneously with optimized values (table 14-1).

Model calibration is dependant on observations of the groundwater flow system. Because the observations of streamflows relied on historical data, a quantitative analysis of model calibration was not realistic. However, the general nature of streamflows into and out of the Kabul Basin are known and groundwater-level data were available (Akbari and others, 2007), which allow for an approximate calibration (fig. 14-1) and analysis of model parameter sensitivity (table 14-1). Observations are used to find the best-fit model parameters, and the known or estimated error of the observations are used to calculate the sensitivity of the groundwater flow model to the model parameters. Observations include measured or estimated groundwater heads and groundwater discharges (base flows). Age of groundwater samples was used qualitatively as an observation. Although observation error is rarely known in practice, it can be estimated and parameter values are generally not very sensitive to moderate changes in the weights used (Hill, 1998). By this process, data sets with greater accuracy are given greater weight in the parameter-estimation process; this permits data sets with different levels of accuracy to be used simultaneously in the parameter-estimation process. The steady-state parameter sensitivity was calculated with all model layers simulated as non-convertible (saturated) layers to “linearize” the numerical calculations. Although in the natural system some areas are likely to become unsaturated, simulating all layers in the numerical model as saturated (non-convertible), greatly simplifies the numerical calculations allowing for solution of the parameter sensitivities. The simplification (linearization) approach used in this study is presented as a guideline for effective model calibration described by Hill (1998). Groundwater-flow simulations used to assess water availability in the Kabul Basin were conducted with model layer 1 unconfined (convertible).

Approximate weights were assigned to observation groups to represent data with differing accuracies. Groundwater levels (heads) used in model calibration were obtained from three sources to provide aerially distributed calibration points: (1) observations collected by Danish Committee for Aid to Afghan Refugees (DACARR) during recent (post-2000) shallow-well installations (Safi and Vijselaar, 2007); (2) a historical well database containing water levels collected during installation of supply wells primarily in the 1970s and 1980s, also maintained by DACAAR (Eng. Hassan Saffi, DACAAR, written commun., 2007); and (3) and water levels monitored by Afghanistan Geological Survey (AGS) (Akbari and others, 2007). Groundwater elevations derived from the first two data sets were calculated by subtracting depth to water from the measurement point, which in this case was the model cell surface elevation (interpreted from the DEM). The first data set was considered to be accurately located, the second data set was approximately located from street addresses, and the third data set was accurately located (Akbari and others, 2007). The measurement-point elevation is the primary source of water-level error in this data set; therefore, the completion report water-level data are weighted on the basis of measurement-point accuracy. Given the uncertainties involved in well location and measurement, a standard deviation of 10 m was used for water-level observations from the first 2 data sets, and 1-m for the third.

The Kabul Basin groundwater balance was simulated using the mean annual base flow (table 8) as inflows to the rivers entering the basin (fig. 4). Simulated base flows out of the basin were calculated at the Panjsher (2,260,000 m^3/d) and Kabul Rivers (550,000 m^3/d), at the model boundary (fig. 4), and were comparable to median annual outflows (2,984,000 and 856,000 m^3/d, respectively) in table 8. The model more closely represents median flow conditions and the median flows are probably a better indicator of long-term groundwater-flow conditions than mean flows. The hydraulic properties for sediments and rocks, described in appendix 6, and the rate of recharge and irrigation leakage were adjusted, in a parameter estimation and user guided iterative process, to calibrate the conceptual model to mean flows and heads. Regionally simulated hydraulic properties and the sensitivity of the simulated groundwater flow to selected model parameters are provided in table 14-1.

Simulated groundwater levels compared favorably to historical groundwater-level observations by subbasin (fig. 14-1). Simulated groundwater levels in the valley bottoms, or subbasin centers, were generally within 10 m of historic or recent mean values. However, larger errors were apparent near the valley walls where some heads were much lower than the observations. This illustrates a common difficulty of representing a valley-aquifer system, with considerable relief, with a numerical groundwater-flow model. Errors in simulated heads at the valley walls indicate also that the conceptualization of the groundwater flow system, at this location in the model, and the magnitude and distribution of groundwater inflows from the adjacent bedrock hillsides, is not well known. The conceptual model parameters with the greatest sensitivity include (table 14-1): streambed conductance, areal recharge, K3 (loess horizontal hydraulic conductivity), K8 (sedimentary rock horizontal hydraulic conductivity), K5 (upper Neogene horizontal hydraulic conductivity), K6 (lower Neogene horizontal hydraulic conductivity), and GBH (general head boundary). The conceptual model was least sensitive to model parameters representing vertical conductivities. This can be expected given that there are few stresses with depth and no measurements of vertical head gradients. A number of parameters have an upper and (or) lower 95-percent confidence interval more than a few orders of magnitude from the parameter value (table 14-1). This reflects the fact that there are few or no observation data with which to qualify or constrain some parameters.

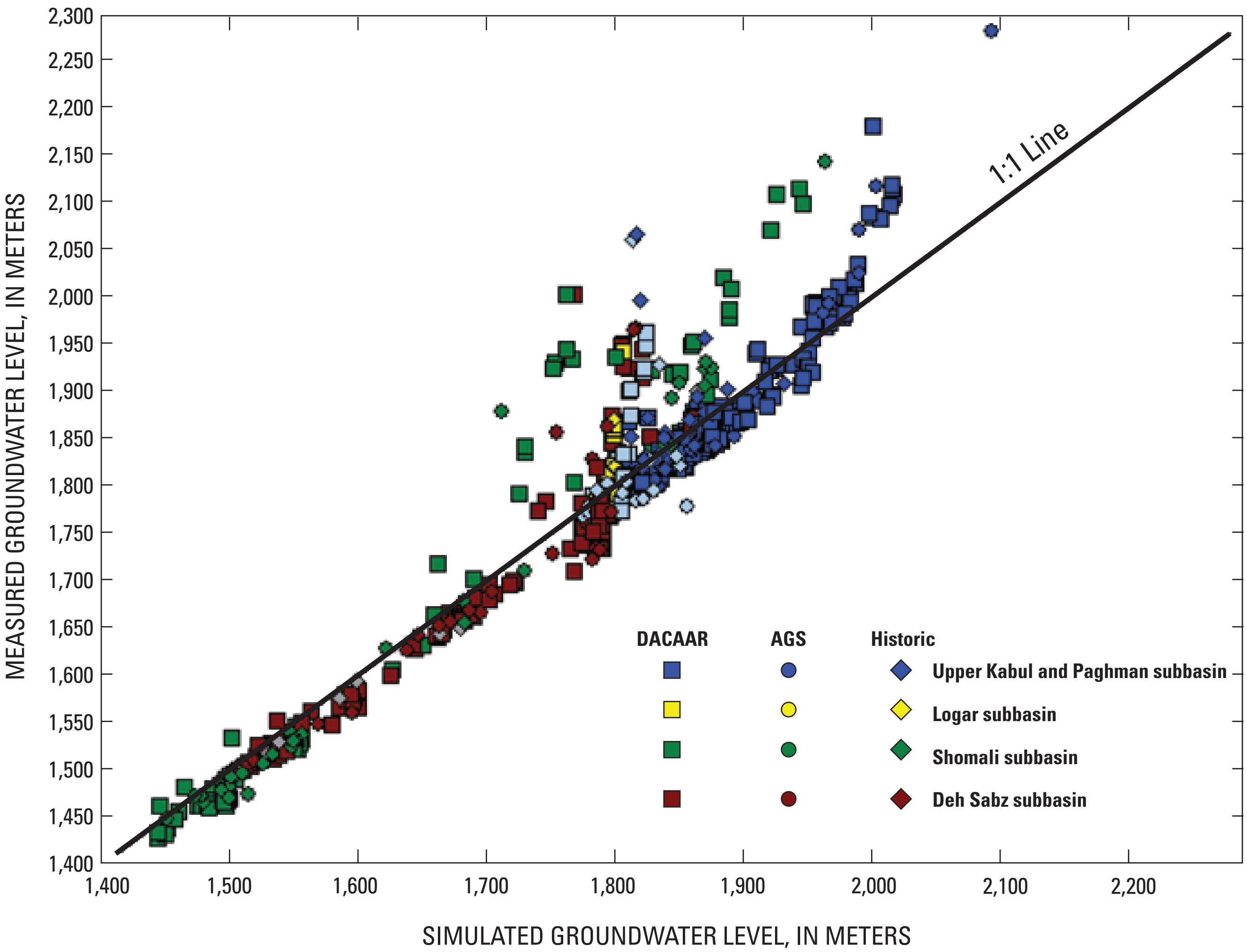

Figure 14-1. Observed and simulated groundwater levels in the Kabul Basin, Afghanistan. Data points include water levels measured by the Danish Committee for Aid to Afghan Refugees (DACAAR), the Afghanistan Geological Survey (AGS), and at water-supply wells installed before 1980 (Historic)

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