Prepared in cooperation with the U.S. Agency for International Development

Inventory of Ground-Water Resources in the Kabul Basin, Afghanistan

USGS Afghanistan Project Product No. 001

Scientific Investigations Report 2005-5090

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

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Contents

Figures

Tables

Conversion Factors and Datum

Multiply	By	To obtain
kilometer (km)	0.6214	mile
liter (L)	0.264	gallon
liter per second (L/s)	15.85	gallon per minute
meter (m)	3.281	foot
meter (m)	1.094	yard
meter per day (m/d)	3.281	foot per day
meter squared per day (m^2/d)	10.76	foot squared per day
milliliter (mL)	0.03381	ounce, fluid
millimeter (mm)	0.03937	inch
square kilometer (km^2)	247.1	acre

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

$$°F = (1.8 \times °C) + 32$$

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

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

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

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The story of Afghanistan is a story of juxtaposition—a long history of colliding landmasses and colliding cultures that continues unabated. J. Stephen Schindler (2002)

Abstract

In 2004, the U.S. Geological Survey began working with engineers at the Afghanistan Geological Survey to provide hydrologic training and equipment and to apply these tools to build an inventory of water wells in the Kabul Basin of Afghanistan. An inventory of 148 wells now includes information on well location, depth, and access. Water-level and water-quality measurements have been made at most of these wells. A water-level elevation map has been constructed, and general directions of ground-water flow have been defined.

Ground-water flow in the Kabul Basin is primarily through saturated alluvium and other basin-fill sediments. The water-table surface generally mirrors topography, and ground water generally flows in the directions of surface-water discharge. The quality of ground water in the Kabul Basin varies widely. In some areas, ground-water quality is excellent, with low concentrations of dissolved solids and no problematic constituents. In other areas, however, high concentrations of dissolved solids and the presence of some constituents at concentrations deemed harmful to humans and crops render untreated ground water marginal or unsuitable for public supply and/or agricultural use. Of particular concern are elevated concentrations of nitrate, boron, and dissolved solids, and an indication of fecal pollution in some parts of the basin.

As Afghanistan emerges from years of conflict, as institutional capacities rejuvenate and grow, and as the need for wise water-management decisions continues, adequate data and a fuller understanding of the ground-water resource in the Kabul Basin will be imperative. The work described in this report represents only a modest beginning in what will be a long-term data-collection and interpretive effort.

Introduction

Political upheaval, military invasion, civil war, religious extremism, population displacement, and drought—Afghanistan has been overwhelmed with tragedy during recent decades. In their search for a peaceful future, the Afghan people face many difficulties. One of the country's most critical needs is to secure safe and reliable supplies of water. The situation is particularly acute in major population centers, such as Kabul, Herat, Kandahar, and Mazar-e-Sharif, and in rural agricultural areas reliant on irrigation. The problem has become so pronounced that it affects international efforts to stabilize the country and is widely viewed as a national health and humanitarian crisis (Refugees International, 2004; Action Contre la Faim, 2004).

In 2004, the U.S. Geological Survey (USGS), under an agreement funded by the U.S. Agency for International Development (USAID), began a collaboration with a group of water engineers at the Afghanistan Geological Survey (AGS). In both domestic and international arenas, it is the mission of the USGS to develop the data and understanding necessary for the wise management of natural resources. The AGS has a similar mission in its homeland. Unfortunately, for the tragic reasons cited above, the ability of the AGS and other Afghan agencies to address the nation's water crisis has been limited. Ministries have lacked equipment and personnel trained in modern hydrologic techniques, and much historic data have been lost.

The initial focus of the AGS-USGS collaboration has been on training, procurement of equipment, and application of these tools to build an inventory of water wells in the Kabul Basin. Training and equipment are being provided in computer science, data base management, geographic information systems, geographic positioning systems, field hydrogeology, and water quality. Almost 150 wells in the Kabul Basin have been inventoried as of November 2004. In most of these wells, water levels have been measured, and water samples have been collected and analyzed for physical, chemical, and microbiological properties. This report presents the results of this initial data-collection effort.

Acknowledgments

The authors acknowledge the efforts of many individuals whose contributions have made this work possible. Said Mirzad, senior national resources advisor to the U.S. Ambassador to Afghanistan, was instrumental in building a cooperative framework between AGS and USGS. Charles Moseley and Peter Jezek of USAID worked tirelessly with Jack Medlin and Verne Schneider of the USGS to complete the agreement. John Earle, David Litke, and Patrick Tucci were integral members of the USGS team. Finally, it is with the utmost gratitude and affection that we acknowledge the resilience, dedication, and hard work of our Afghan colleagues.

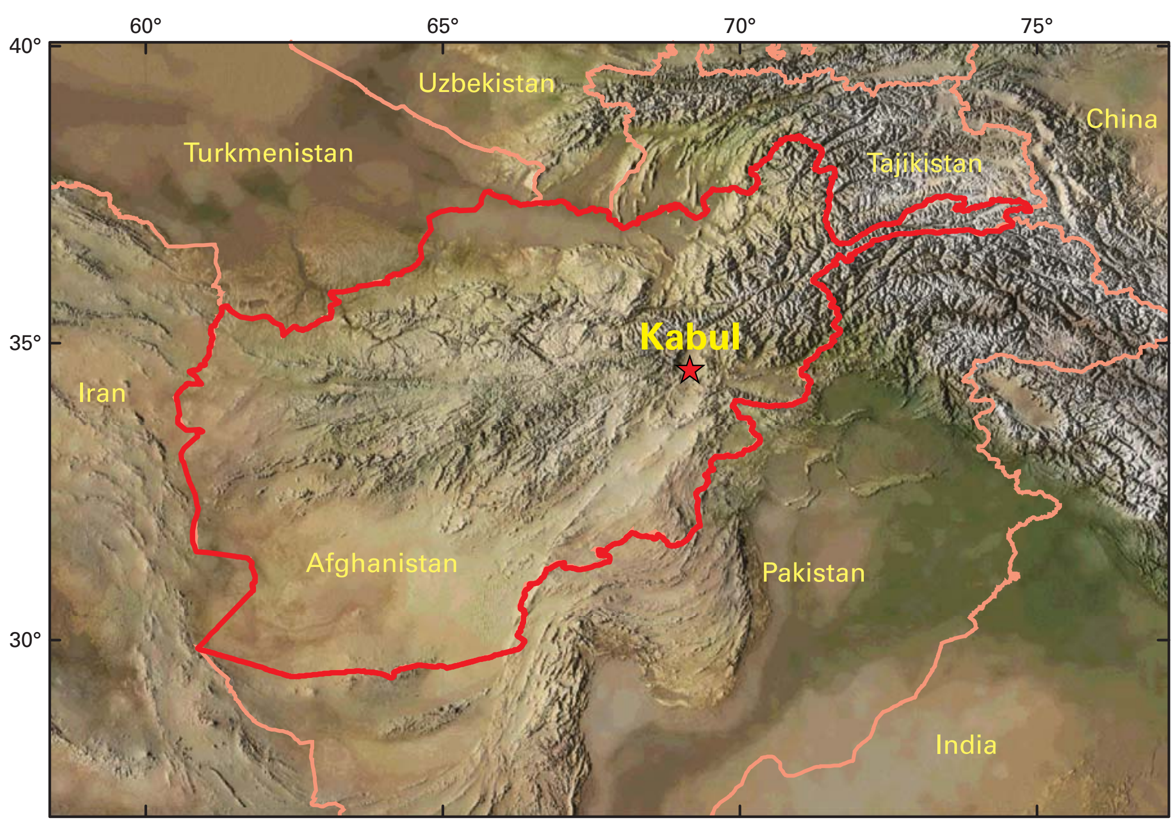
Description of the Study Area

The study area encompasses about 1,800 km^2 and includes the Kabul Basin (figs. 1 and 2). This section describes the geographic setting, climate, and geologic framework, which affect occurrence, flow, and quality of ground water.

Geographic Setting

Afghanistan is a rugged, land-locked country in south-central Asia (fig. 1). It is bordered by Pakistan, Iran, Turkmenistan, Uzbekistan, Tajikistan, and China. Its terrain is dominated by the majestic Hindu Kush, whose peaks rise to over 7,000 m, and associated mountain ranges extending across the country in a northeast to southwest arc. Traversed by deep valleys, these mountains separate plains to the north and southwest.

The city of Kabul is located along the confluences of the Kabul River, Logar River, and Paghman Stream (fig. 2), although in recent years these streams have been dry for much of the year. Paghman Stream joins the Kabul River at the western end of the city, just before the Kabul River enters central Kabul. Topography in central Kabul is relatively flat. The Kabul River flows eastward toward its confluence with the Logar River, then enters a steep canyon at the south-central end of the basin. Immediately north of Kabul, bedrock outcrops delineate surface-water divides beyond which ephemeral drainages discharge to the northeast from Shomali and to the northwest from Deh Sabz. Both of these areas eventually contribute flow to the Panjsher River. The Panjsher River joins the Kabul River approximately 100 km east of Kabul.



Base from U.S. Geological Survey digital data series DDS-62-C, 2001
GCS World Geodetic System 1984

Figure 1. Location of Afghanistan and Kabul.

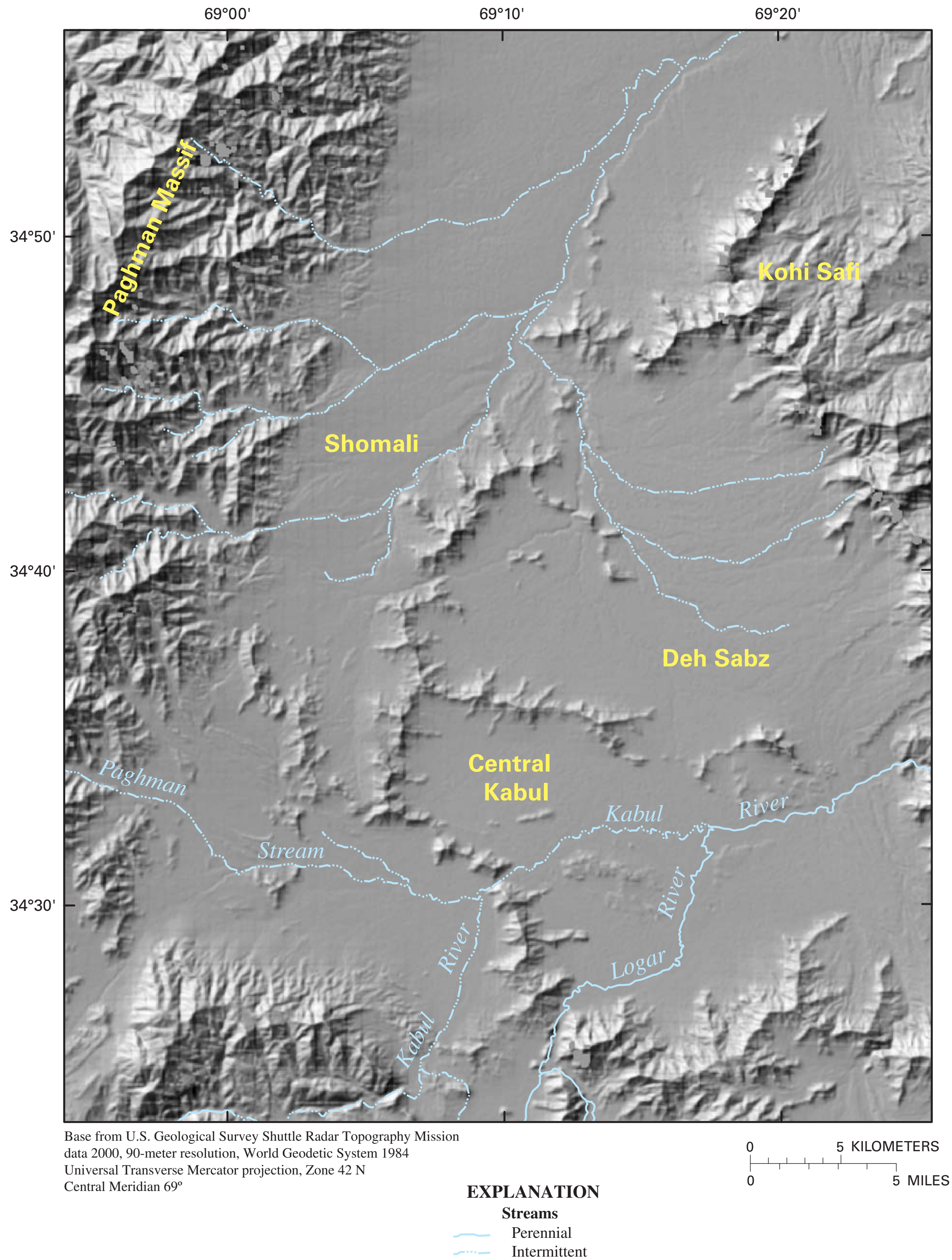


Figure 2. Study area of Kabul Basin, Afghanistan, with major surface-water features.

Climate

The climate in Afghanistan is arid to semi-arid, with cold winters and hot summers. Meteorological records have been scarce in recent decades, but from the period 1956 to 1983, Kabul experienced temperatures ranging from a mean monthly low in January of -7.1°C to a mean monthly high in July of 32.1°C (table 1). During this same period, mean annual precipitation in Kabul was 312 mm (World Meteorological Organization, 2004). However, since about 1998, most of the country has experienced drought conditions. Annual precipitation in Kabul for 2001, for example, was reported at only 175 mm (International Water Management Institute, 2002). The ongoing drought has been described as the worst in Afghanistan in over a century (Girardet and Walter, 2004).

Table 1. Climatological information for Kabul, Afghanistan.

[From World Meterological Organization climatological normals based on monthly averages for the period 1956 to 1983. °C, degree Celsius; mm, millimeters]

Month	Mean temperature (°C)		Mean total
	Daily minimum	Daily maximum	Precipitation (mm)
Jan.	-7.1	4.5	34.3
Feb.	-5.7	5.5	60.1
Mar.	0.7	12.5	67.9
Apr.	6.0	19.2	71.9
May	8.8	24.4	23.4
June	12.4	30.2	1.0
July	15.3	32.1	6.2
Aug.	14.3	32.0	1.6
Sept.	9.4	28.5	1.7
Oct.	3.9	22.4	3.7
Nov.	-1.2	15.0	18.6
Dec.	-4.7	8.3	21.6

Geologic Framework

Afghanistan lies along the great tectonic upheaval that has produced the world's highest mountain ranges—the Himalaya, Karakoram, Pamirs, and the Hindu Kush. In the Kabul area, orogeny has been accompanied by a complex sequence of faulting. Deep crystalline grabens formed and have filled with hundreds of meters of alluvial, colluvial, and lacustrine deposits (Bohannon, 2005) (figs. 3a and 3b).

The landmass of Afghanistan is a collection of crustal blocks that separated about 200 million years (m.y.) ago during the fragmentation of the supercontinent Pangea. A series of collisions between small crustal blocks, derived from the southern landmass of Gondwana, and the large northern landmass of Laurasia lasted from about 100 m.y. to 5 m.y. ago (Treloar and Izatt, 1993). The result is the very complex and varied geology within the borders of present-day Afghanistan. Many block boundaries are marked by suture zones, some of which display recurring movement along prominent strike-slip faults and fault zones, and some of which nearly transect the entire country.

The Kabul block is bounded on the east and west by major left-lateral strike-slip faults, and by a thrust fault at depth on the north (Myslil and others, 1982; Treloar and Izatt, 1993). The strike-slip displacement on east- and west-bounding faults has moved the Kabul block in a northeasterly direction. The general stratigraphic sequence in the Kabul block is comprised of Proterozoic metamorphic rocks overlain by Paleozoic to Cenozoic (Pliocene) sedimentary rocks (Wolfart and Wittekindt, 1980). Major river valleys are filled with Pleistocene through Holocene sediments (Banks and Soldal, 2002). Igneous rocks were intruded periodically from the late Cretaceous to the Tertiary (Oligocene) and were later exposed by erosion and/or tectonic activity.

The Kabul Basin is located in the north-central part of the Kabul block. The Kabul Basin was formed by faulting of crystalline rocks and erosion. Faulting uplifted the surrounding mountains and hills relative to the basins. Subsequent erosion of these highlands and deposition in the basin grabens resulted in the present landscape. This landscape and its underlying geology is similar to the basin and range provinces of Arizona and Nevada in the United States.

The basin is bordered on the west by the Paghman Massif (fig. 2) comprised of Proterozoic and Mesozoic crystalline rocks, and Paleozoic and Mesozoic sedimentary rocks (Bohannon, 2005), which are highly faulted. The Kohi Safi mountain range borders the basin on the east and northeast and is comprised of Proterozoic and Paleogene crystalline rocks, Paleozoic sedimentary rocks, and Mesozoic (Triassic) rhyolitic lavas (Bohannon, 2005). The hills to the south of the basin are comprised of late Paleozoic and Mesozoic (Triassic) sedimentary rocks and Cenozoic (Eocene) ultramafic intrusive rocks (Bohannon, 2005). The low hills within the Kabul Basin are comprised of Proterozoic gneiss and are surrounded by an apron of late Cenozoic (Pleistocene-Holocene) alluvial fan material. The geologic map and schematic cross sections in Myslil and others (1982) depict steeply dipping range-front faults controlling the low hills within the basin and offsetting some of the older alluvial deposits. The initial development of these graben structures began in the late Miocene, which is coincident with the formation of the Kabul River valley (Myslil and others, 1982). Formation of the grabens was accompanied by erosion of the surrounding upland areas and the filling of the developing basins with sediments.

Detailed stratigraphic information about the basin-fill material and the bedrock underlying the basin sediments is scarce. The most comprehensive description of the basin-fill material to date is by Myslil and others (1982). According to that report, and to a certain degree confirmed by the geologic map compiled by Bohannon (2005), the stratigraphic sequence for the basin fill is: Miocene conglomerate and sandstone (Butkhak Formation); Pliocene clays, lacustrine siltstone, and lenses of very fine sand (Kabul Formation); and Quaternary sediments of middle to upper Pleistocene age. Bohannon (2005) further divides the Quaternary sediments within the Kabul Basin. Four units labeled as "conglomerate and sandstone" ranging in age from middle Pleistocene to Holocene are mapped. Limited exposures of a middle Pleistocene unit occur at the bedrock-alluvium contact along the flanks of the mountains on the east and west sides of the basin. The unit with the greatest areal extent, covering most of the basin surface, is a late Pleistocene alluvial unit described as "shingly and detrital sediments, gravel, sand > silt and clay," with loess occurring over much of the mapped area. Late Pleistocene to Holocene alluvial fan deposits are prominent features within the basin, especially on the low hills comprised of Proterozoic gneiss. The youngest Quaternary unit occurs in and adjacent to the active drainage channel of the Kabul River and its major tributaries.

The lack of borehole lithologic or geophysical data limits a refined conceptualization of the subsurface geology of the basin. The thickness of basin-fill sediments cannot be accurately determined at this time, because no known boreholes have penetrated the full thickness of sediments to the underlying bedrock. The thickness and lateral extent of individual lithostratigraphic units are also unknown at this time. Using the schematic cross sections in Myslil and others (1982), and an understanding of the concepts of basin development, the thickness of the basin-fill sediments can be estimated. The greatest thickness of the basin-fill sediments is in the center of the basins where, in some areas, it is in excess of 600 m. The thickness decreases towards the range-front faults, but is still on the order of tens of meters adjacent to the outcrops of bedrock bordering and within the basin. A thin covering of sediments generally occurs at the bedrock-alluvium contact at the edges of the basins. The general stratigraphic sequence for basin-fill sediments in Afghanistan is described in Banks and Soldal (2002). Adjacent to and directly overlying bedrock outcrops, the sediments consist of coarse-grained alluvial fan deposits. From the basin-bounding and inter-basin mountains toward the center of the basin, the size of the sediments decreases to sand-, silt-, and clay-sized. Depending on the depositional environment, areas within the basin could contain substantial thicknesses of lacustrine and/or evaporate deposits. This conceptual model is consistent with alluvial basins in other semi-arid environments (Anderson and others, 1992; Bartolino and Cole, 2002). The active river channels generally contain sediments ranging in size from coarse gravel to fine sand. There were no indications in any of the references examined for this report that any boreholes had been drilled deep enough to penetrate the basin-fill sediments and encounter bedrock in the Kabul Basin.

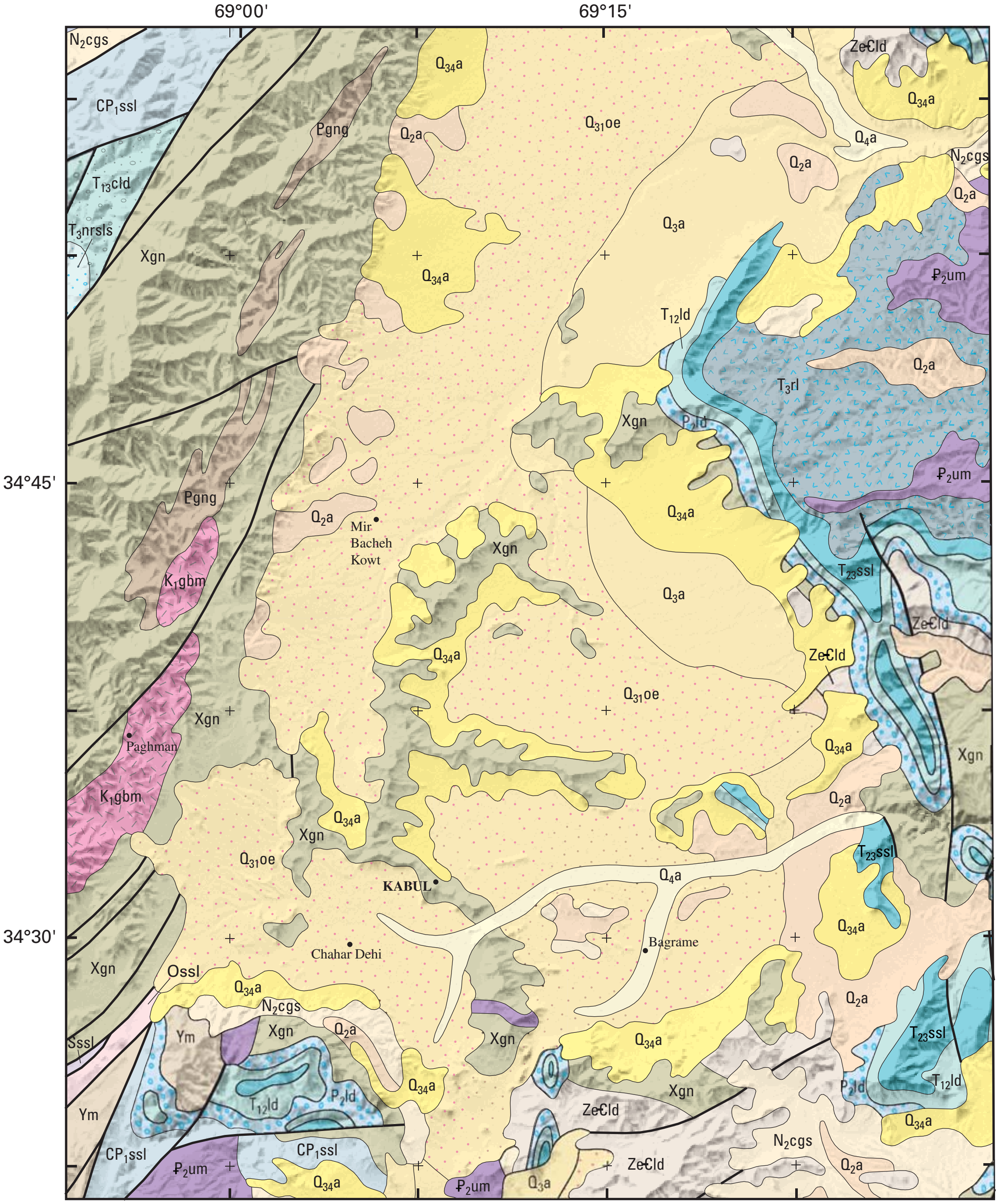
Myslil and others (1982) list three hydrogeologic units within the Kabul Basin—crystalline rocks and their mantle, Tertiary sediments, and Quaternary sediments. The crystalline rocks are the Proterozoic metamorphic rocks. Secondary fracture permeability in these rocks resulting from faulting could make these rocks potentially important water-bearing zones in and adjacent to the Kabul Basin. In the absence of fractures, the crystalline rocks act as a barrier to ground-water flow. The Tertiary sediments, referred to as Neogene by ground-water engineers at the AGS, are primarily clay, clay-silt, and fine sand-clay sediments. Some of the fine sand-clay layers are potential aquifers, but their areal extent is unknown and could be limited. The Tertiary (Neogene) sediments are not considered a major aquifer in the Kabul Basin. Future drilling and hydraulic testing of boreholes could improve understanding of the water-producing abilities of these Tertiary sediments. The Quaternary alluvial deposits within the major rivers channels are the most productive deposits in the Kabul Basin, as evidenced by a number of municipal production wells drilled in this environment.

Previous Hydrogeologic Investigations

Little published information on the hydrogeology of the Kabul Basin is available in English or any other language. Myslil and others (1982) produced a water-table map of the Kabul area and briefly described the hydraulic properties and water quality of the aquifer. Transmissivity was reported to range from 10 to 8,000 m^2/d. Based on a small number of chemical analyses, ground water in the basin was described as being variably mineralized. In zones of lower levels of mineralization, waters were of the calcium bicarbonate type. In more mineralized zones, waters were more enriched in sodium and chloride.

Shevchenko and others (1983) described the hydrogeology of productive alluvial deposits along the Kabul River in the Darlaman area of southwest Kabul. Alluvium in this area consisted of gravels and conglomerates at least 55 m thick. Measures of hydraulic conductivity ranged from 46 to 105 m/d. Yields of as much as 70 L/s were accompanied by drawdowns of less than 10 m. Dissolved-solids concentrations were reported at less than 700 mg/L.

Banks and Soldal (2002) reported declines in water-table elevation of 4 to 6 m in the Kabul area as a result of the first 3 to 4 years of the drought. Citing the work of Hamid (2002), Najibullah (1996), and Timmins (1996), Banks and Soldal (2002) described hydraulic conductivity in the basin of 10 to 70 m/d; well yields ranged from 5 L/s in fine-grained Neogene (Tertiary) sediments to several tens of liters per second in coarser grained Quaternary deposits. Timmins (1996) analyzed for nitrate and *Escherichia coli* (*E. coli*) in 1,400 wells, springs, and tap stands in the Kabul area. In this survey, the average nitrate (as N) concentration was 9.4 mg/L; 10.8 percent of samples exceeded the U.S. Environmental Protection Agency (USEPA) drinking-water standard of 10 mg/L as N (U.S. Environmental Protection Agency, 2004). *E. coli* counts exceeded 5 colonies per 100 milliliter (col/100 mL) in 45 percent of wells with hand pumps and in 76 percent of open, dug wells.



Base from U.S. Geological Survey OFR 2005-1107
data 2000, 90-meter resolution, World Geodetic System 1984
Universal Transverse Mercator projection, Zone 42 N
Central Meridian 69º

Geology from Bohannon, 2005

Figure 3a. Geology of the Kabul Basin, Afghanistan.

Erathem	Stratigraphic Units	DESCRIPTION OF UNITS
CENOZOIC	Q_4a	**Conglomerate and sandstone (Holocene)—**Alluvium: shingly and detrital sediments, gravel, sand more abundant than silt and clay
	$Q_{34}a$	**Conglomerate and sandstone (Late Pleistocene-Holocene)—**Alluvium: shingly and detrital sediments, gravel, sand more abundant than silt and clay
	Q_3a	**Conglomerate and sandstone (Late Pleistocene)—**Alluvium: shingly and detrital sediments, gravel, sand more abundant than silt and clay
	$Q_{31}oe$	**Loess (Late Pleistocene)—**Loess more abundant than sand, clay
	Q_2a	**Conglomerate and sandstone (Middle Pleistocene)—**Alluvium: shingly and detrital sediments, gravel, sand more abundant than silt and clay
	N_2cgs	**Conglomerate and sandstone (Pliocene)—**Gray conglomerate, grit, sandstone more abundant than siltstone, clay, limestone, marl; gypsum, salt; acid to mafic volcanic rocks
	₽$_2$um	**Ultramafic intrusions (Eocene)—**Dunite, peridotite, serpentinite
MESOZOIC	K_1gbm	**Gabbro and monzonite (Early Cretaceous)—**Gabbro, monzonite more abundant than diorite, granodiorite
	T_3rl	**Rhyolite lava (Late Triassic)—**Shale more abundant than phyllite, andesite to basalt (greenstone altered), limestone (Kotagai Series)
	T_3nrsls	**Siltstone and sandstone (Late Triassic-Norian/Rhaetian)—**Siltstone, sandstone more abundant than shale, conglomerate
	$T_{23}ssl$	**Sandstone and siltstone (Middle-Late Triassic)—**Sandstone and siltstone more abundant than mudstone, carbonaceous shale, limestone, marl, conglomerate, acid and mafic volcanic rocks (North Afghanistan); limestone, dolomite, marl (Kabul Massif and Kunar Tectonic Zone)
	$T_{13}cld$	**Limestone and dolomite (Early-Late Triassic/Carnian)—**Limestone, dolomite more abundant than conglomerate, chert, marl (Middle Afghanistan); limestone, sandstone, shale, conglomerate, chert, mafic volcanic rocks (Khashrud Tectonic Zone); limestone, dolomite (Kishmaran Tectonic Zone)
	$T_{12}ld$	**Limestone and dolomite (Early-Middle Triassic)—**Limestone, dolomite, marl
PALEOZOIC	P_2ld	**Limestone and dolomite (Late Permian)—**Limestone, dolomite more abundant than marl, conglomerate, sandstone, siltstone, shale, bauxite and bauxite-bearing rocks
	CP_1ssl	**Sandstone and siltstone (Carbonifeous-Early Permian)—**Sandstone and siltstone more abundant than slate, andesite to basalt volcanic rocks
	Sssl	**Sandstone and siltstone (Silurian)—**Sandstone, siltstone, shale (Lagar and Argandab Tectonic Zones)
	Ossl	**Sandstone and siltstone (Ordovician)—**Sandstone and siltstone more abundant than shale (Lagar and Argandab Tectonic Zones); limestone, sandstone, siltstone, shale (Middle Afghanistan); shale, sandstone, chert (North Afghanistan)
	Ze€ld	**Limestone and dolomite (Neoproterozoic-Edicarian/Cambrian)—**Limestone and dolomite (Argandab Tectonic Zone); [ZEmbq: marble, quartzite, metasandstone, mica schist {Kabul Massif}]
PROTEROZOIC	Ym	**Metamorphic rocks—undivided (Mesoproterozoci)—**Greenschist, gneiss, quartzite, marble, amphibolite {metavolcanic lava and sedimentary rocks}
	Pgng	**Gneiss and granite (Proterozoic)—**Gneiss-granite, granite, plagiogranite
	Xgn	**Gneiss (Paleoproterozoic)—**Two-mica, biotite, biotite-amphibole, garnet-biotite, and plagioclase gneiss; migmatite, quartzite, marble amphibolite
	———	**Fault or fault zone**

Figure 3a. Geology of the Kabul Basin, Afghanistan.—Continued

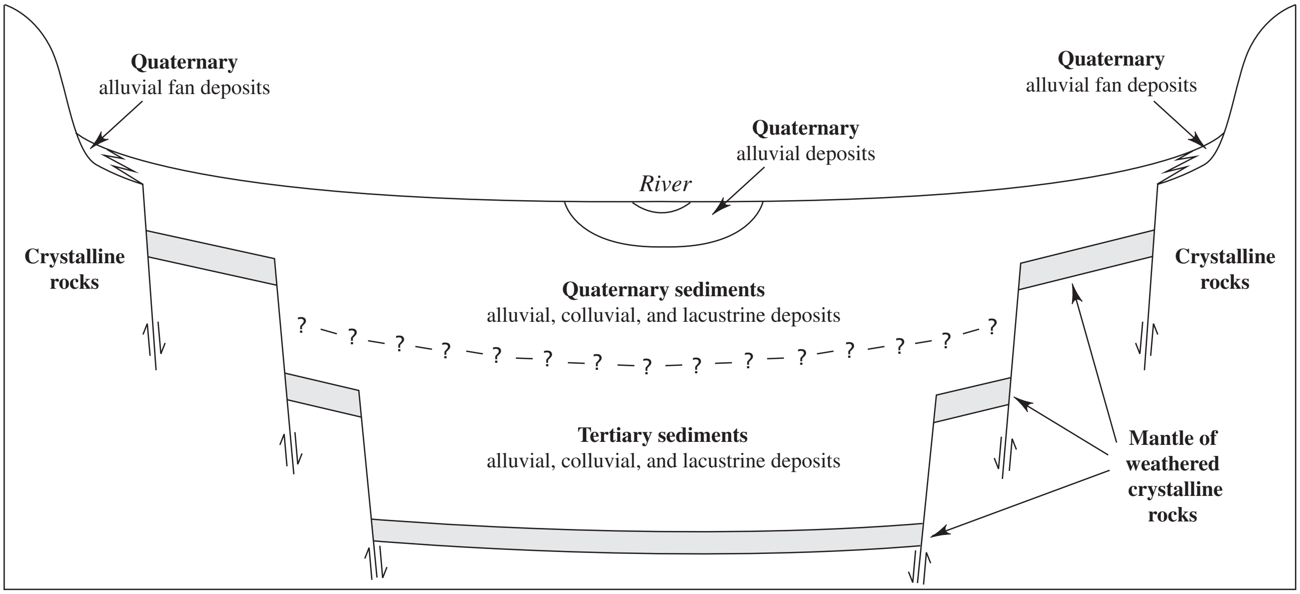


Figure 3b. Generalized section of hydrogeologic units.

The U.S. Army Corps of Engineers (2002) tabulated ground-water resources throughout Afghanistan. In the Kabul area, they briefly described sand and gravel alluvial aquifers along the Kabul and Logar Rivers as well as along the Paghman Stream. Aquifer thickness was reported to range from a few meters to 150 m. Well yields were described as moderate to large with pumpage of more than 40 L/s with small drawdown in the lower Kabul alluvial aquifer. Water-quality concerns included locally brackish to saline conditions and microbial contamination of shallow ground water.

Methods

An inventory of 148 wells was compiled for the Kabul Basin. Locations of these wells are shown in figures 4a and 4b. Wells were chosen to provide broad spatial coverage, with additional emphasis on selecting deeper wells and those with secure, sustainable access. Shallow wells, such as the scores of hand-pumped public-supply wells constructed by relief organizations, were largely excluded from the inventory. Shallow wells were excluded in part because they were the focus of an ongoing investigation by the German Federal Institute for Geosciences and Natural Resources. Basic categories of information sought for each well, such as location, depth, and access, are displayed in table 2.

Table 2. Categories of information sought for each well in the inventory of wells in the Kabul Basin, Afghanistan.

AGS assigned well identification number
Narrative description of well location
Latitude of well, in decimal degrees
Longitude of well, in decimal degrees
Land surface elevation of well, in meters above sea level
Comment on quality of location survey
Depth from land surface to bottom of well, in meters
Name of person who can give permission to access well
Date of well visit
Measured depth to water below land surface, in meters
Water-level elevation above sea level, in meters
Comment on local pumping conditions

Well locations were established by differential global positioning system (GPS) measurements using Garmin 76S instruments and Rhino-Rover software developed by U.S. Positioning Inc. The three-dimensional satellite survey originated from a benchmark provided by The Louis Berger Group, Inc. (Ed Coban, oral and written commun., September 13, 2004). This benchmark has been used for road construction and for a survey of wells and other structures by international agencies in Kabul. A derivative base station was established at the AGS building in Kabul. Locations of all wells in the network were surveyed by collecting 30 minutes of spatial data at 1-second intervals from 6 to 9 satellites. Satellite quality-control data were obtained from the continuously operating reference stations operated by the National Geodetic Survey (http://www.ngs.noaa.gov/CORS). Post-processing of the resulting files was accomplished with the Rhino-Rover software operating in carrier phase. Uncertainty of ground-surface measurement in all three spatial dimensions at each well site is believed to be less than 1 m.

Depth to ground water from the surveyed ground surface was determined by down-hole measurements using electric water-level tapes. Water-table altitude was calculated by subtracting the measured depth to water from the land-surface altitude, and the water-table altitude was plotted on a base map. Water-level measurements were made between late July and late November 2004. With few exceptions, it is believed that natural or human induced changes in the water-table surface during this 4-month time period were less than the 1-m accuracy of the survey. Multiple measurements of water levels in many wells during this period substantiate this assumption. Therefore, for the purposes of defining the water table in the Kabul area during this period, all static measurements were used. Water levels in six wells (110, 170, 201, 208, 219, and 220) were believed to represent pumping (non-static) levels and were not used in preparation of the water-table map. For exploratory analysis, water levels were contoured using the spatial analyst features of ArcMap (Environmental Systems Research Institute, 1999), but final water-table contour maps were hand drawn.

In addition to water-level measurements, physical, chemical and microbiological properties of ground water were obtained at 108 wells. Water temperature, pH, and specific conductance were measured in the field using a hand-held meter. Dissolved oxygen was determined in the field by a colorimetric method (Hach Company, 2004). Nitrite and nitrate concentration ranges were estimated colorimetrically using field test strips. In addition, water samples were collected in 2- or 4-L high-density plastic containers for chemical analyses; water samples for microbial analysis were collected in 100-mL sterile vessels. These samples were transported on ice to AGS for subsequent processing. Water was filtered using a peristaltic pump and 0.45-micrometer capsule filters. Samples for filtered cation and trace-element analysis were preserved with ultrex nitric acid. Samples for major anion analysis were untreated. Samples for nitrate and nitrite analysis were aspirated into 11-mL vacuum tubes and kept chilled (<4°C) until analysis. At seven wells, additional nitrogen and phosphorus species were determined. Samples were transported to the USGS National Water Quality Laboratory in Lakewood, Colorado, where the chemical analyses were performed according to procedures described in Fishman (1993). Within 6 hours of collection, samples for microbial analysis were processed at the U.S. Embassy in Kabul. The Colilert Quanti-Tray or Quanti-Tray 2000 system was used for enumeration of total coliform bacteria and *E. coli*. All measured water-quality properties and analytes are shown in table 3.

Table 3. Measured water-quality properties and analytes in samples from wells in the inventory of wells in the Kabul Basin, Afghanistan.

[°C, degree Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; µg/L, micrograms per liter]

Field measurements		
Water temperature, °C		
Specific conductance, µS/cm		
pH, standard units		
Dissolved oxygen, mg/L		
Nitrate and nitrite test strip range, mg/L		
Major ions and silica (dissolved, in mg/L)		
Calcium	Alkalinity	
Magnesium	Sulfate	
Sodium	Chloride	
Potassium	Fluoride	
Silica	Bromide	
Residue on evaporation (dissolved, in mg/L)		
Nutrients (dissolved, in mg/L)		
Nitrate	Orthophosphate	
Nitrite	Phosphorus	
Total nitrogen		
Ammonia		
Bacterial indicators (col/100 mL)		
Total coliform		
Escherichia coli		
Trace elements (dissolved, in µg/L)		
Aluminum	Cobalt	Selenium
Antimony	Copper	Silver
Arsenic	Iron	Strontium
Barium	Lead	Thallium
Beryllium	Lithium	Uranium
Boron	Manganese	Vanadium
Cadmium	Molybdenum	Zinc
Chromium	Nickel	

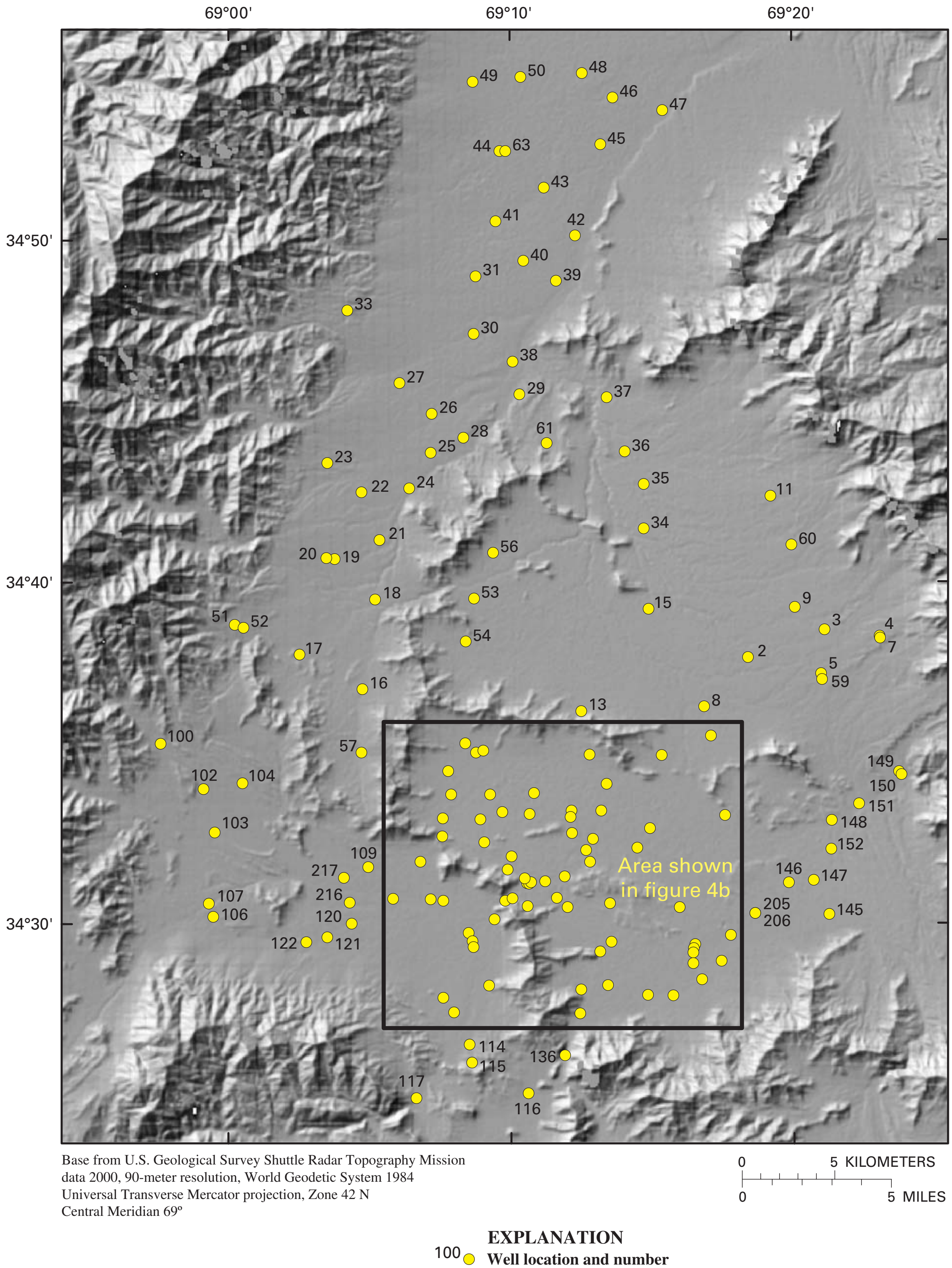
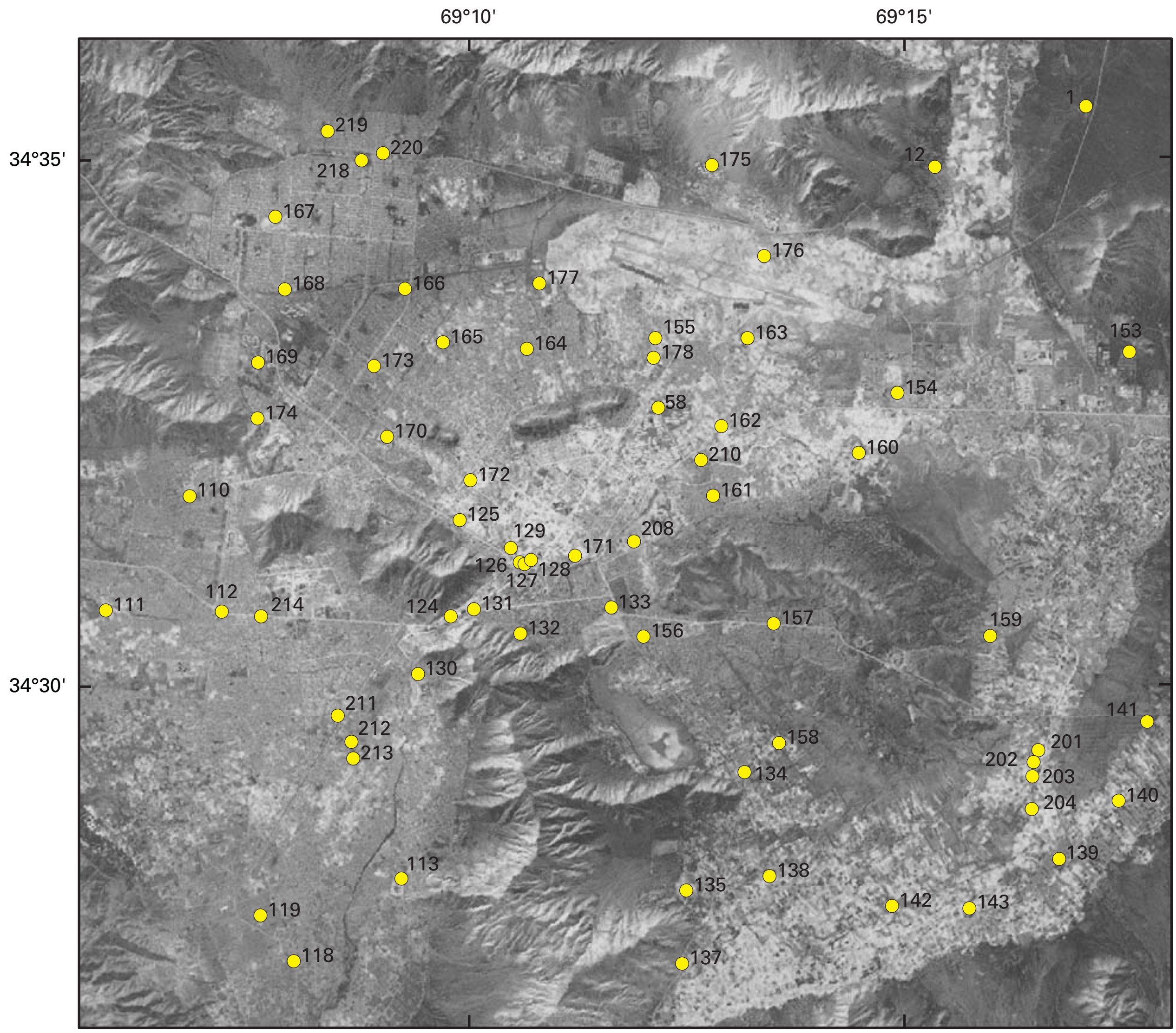


Figure 4a. Location of wells in the ground-water inventory in the Kabul Basin, Afghanistan.



Base from U.S. Geological Survey Shuttle Radar Topography Mission data 2000, 90-meter resolution, World Geodetic System 1984
Universal Transverse Mercator projection, Zone 42 N
Central Meridian 69º

0 1 2 KILOMETERS
0 1 2 MILES

EXPLANATION

137 ○ **Well location and number**

Figure 4b. Location of wells in the ground-water inventory in central Kabul.

Ground-Water Flow in the Kabul Basin

Ground-water flow in the Kabul Basin is primarily through saturated alluvium and other basin-fill sediments. Some ground water may flow through the weathered bedrock immediately beneath the alluvium and through fractures in the bedrock, but the amount of flow in these zones is believed to be small compared with flow in the alluvium. Thus bedrock outcrops effectively isolate ground-water flow into several distinct subbasins.

A water-table map of the Kabul Basin is shown in figure 5. Water-table altitudes range from 2,279 m above sea level in the southwestern part of the basin to 1,466 m above sea level in the northern part of the basin. Water levels in most of central Kabul range from 1,785 to 1,775 m above sea level. Information on vertical ground-water gradients is not available. Water-table contours within the alluvial aquifer were constructed using a 50-m contour interval for most of the study area. Contours were restricted to the alluvium-filled part of the basin, to represent the primary ground-water flow system of the basin. A more detailed water-table map was constructed in central Kabul, using a 5-m contour interval.

The water-table surface generally mirrors topography, and ground water generally flows in the directions of surface-water discharge. Steep gradients exist along mountain-front recharge areas and in the upper reaches of the Kabul, Logar, and Paghman valleys. Gradients decrease across the area beneath central Kabul, in the agricultural and village zones of Shomali, and in the sparsely populated Deh Sabz area.

Water levels from 1980 were mapped by Myslil and others (1982). In comparing water levels measured in this study with those from 1980, a decline in the water table is evident. In the flatter areas of central Kabul, these declines are approximately 5 to 6 m. Water-table declines since 1980 increase to over 10 m in upslope areas. In 1980, marshy areas and a few shallow lakes were present in many parts of central Kabul. During the current study (2004), these marshes and lakes were dry.

Depths to water in the Kabul Basin range from less than 5 m to more than 60 m below land surface (fig. 6). Depths to water are less than 15 m along most stream channels and in most of central Kabul. The water table is within 30 m of land surface throughout most of the basin. Greater depths occur in some areas of Deh Sabz. The greatest depth to ground water was 72 m, a measurement recorded in well 23 located in the foothills of Shomali.

Ground-Water Quality of the Kabul Basin

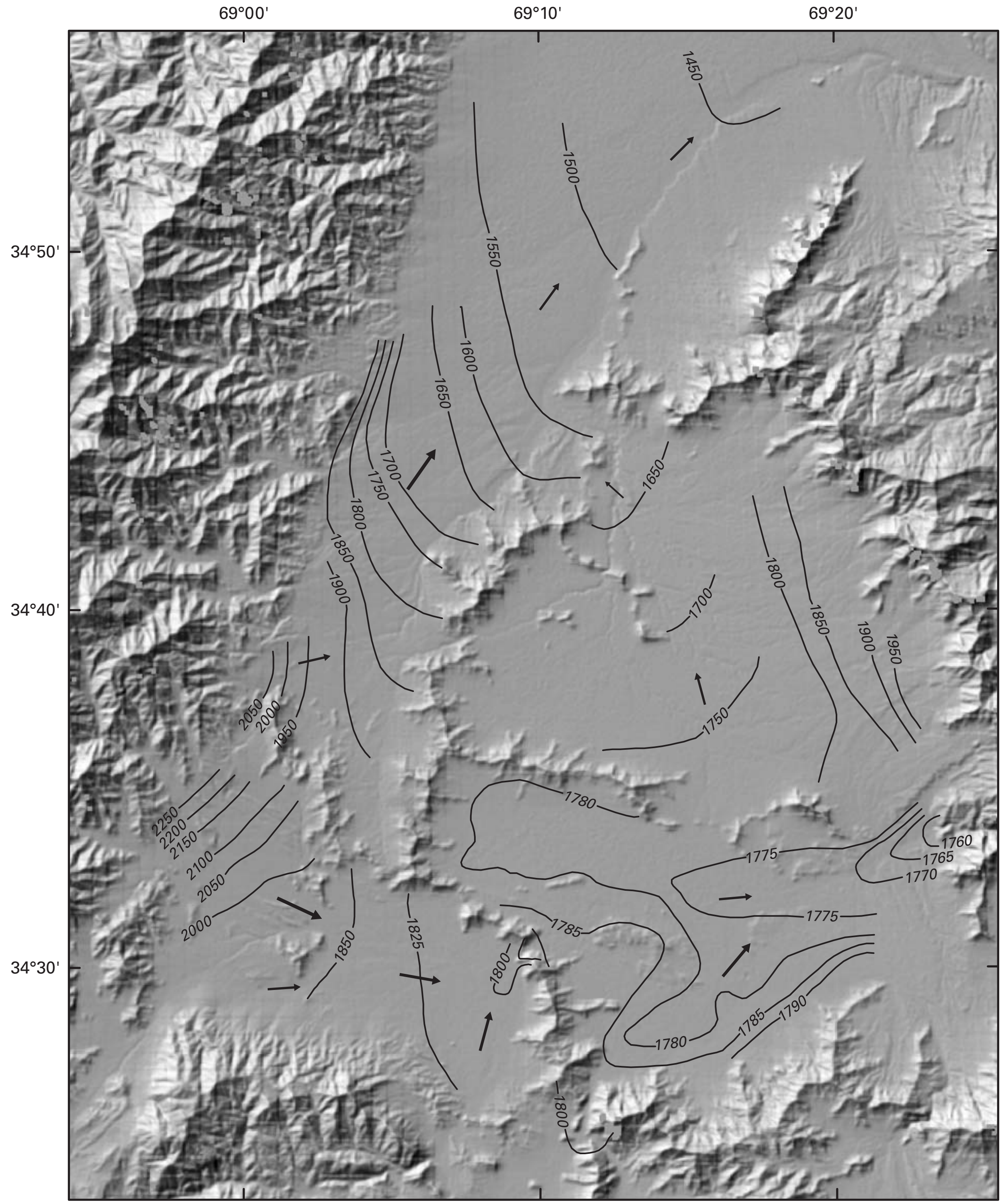
The quality of ground water in the Kabul Basin varies widely. In some areas, ground-water quality is excellent, with low concentrations of dissolved solids and no problematic constituents. In other areas, however, high concentrations of dissolved solids and the presence of some constituents at concentrations deemed harmful to humans and crops render untreated ground water marginal or unsuitable for public supply and/or agricultural use. The results of all water-quality analyses are available on the internet at URL http://pubs.water.usgs.gov/sir2005-5090.

Dissolved Solids, Specific Conductance, and Major Ion Chemistry

Concentrations of dissolved solids in samples collected for this study range from 156 to 9,350 mg/L; the median value is 523 mg/L (fig. 7). Values are generally less than 300 mg/L along upgradient hydrologic boundaries throughout the basin (fig. 8). Along flow paths under less populated areas, these values gradually increase to about 500 mg/L, suggesting natural processes of chemical weathering and minimal anthropogenic impact on major ion chemistry. Under areas of major urban land use, however, gradients of dissolved solids are steeper. Beneath central Kabul concentrations are 500 to 1,000 mg/L or more in many parts of the city. The highest values occur in industrial areas immediately to the northeast of the city, with a single observation (well 153) as high as 9,350 mg/L. While these values are likely influenced by industrial activity, they may also be attributable to natural processes and perhaps to poor well construction. In times of greater local precipitation, marshes were common in several areas on the eastern fringe of the city. These marshes are now dry, leaving a salt crust at the surface. Shallow wells in the area exhibit very high concentrations of dissolved solids (Torge Tuennermeier, Federal Institute for Geosciences and Natural Resources, oral commun., 2004), and deeper wells that are poorly sealed may be affected by recharge through the surficial salt crust.

Values of specific conductance mirror concentrations of dissolved solids. The range is 241 to 14,010 μS/cm; the median value is 849 μS/cm (fig. 9). Specific conductance is less than 500 μS/cm along most upgradient hydrologic boundaries (fig. 10). Under less populated areas, these values gradually increase to 600 to 1,000 μS/cm. Beneath central Kabul they increase to more than 1,000 μS/cm. The highest values occur in industrial areas immediately to the northeast of the city, with a single observation (well 153) as high as 14,010 μS/cm.

Major ion chemistry of the Kabul Basin is predominately of the calcium magnesium bicarbonate type. In ground water with higher dissolved solids, however, sodium, sulfate, and chloride concentrations are elevated. This trend is illustrated in the piper diagram in figure 11, where samples with dissolved-solids concentrations greater than 1,000 mg/L are relatively distinct. Boxplots of major ion concentrations are shown in figure 12.



Base from U.S. Geological Survey Shuttle Radar Topography Mission
data 2000, 90-meter resolution, World Geodetic System 1984
Universal Transverse Mercator projection, Zone 42 N
Central Meridian 69º

0 5 KILOMETERS
0 5 MILES

EXPLANATION

—2100— **Water-table contour—**Shows altitude of water table, in meters above sea level. Contour interval variable.

→ **Generalized direction of ground-water flow**

Figure 5. Water table in the Kabul Basin, Afghanistan, July through November 2004.

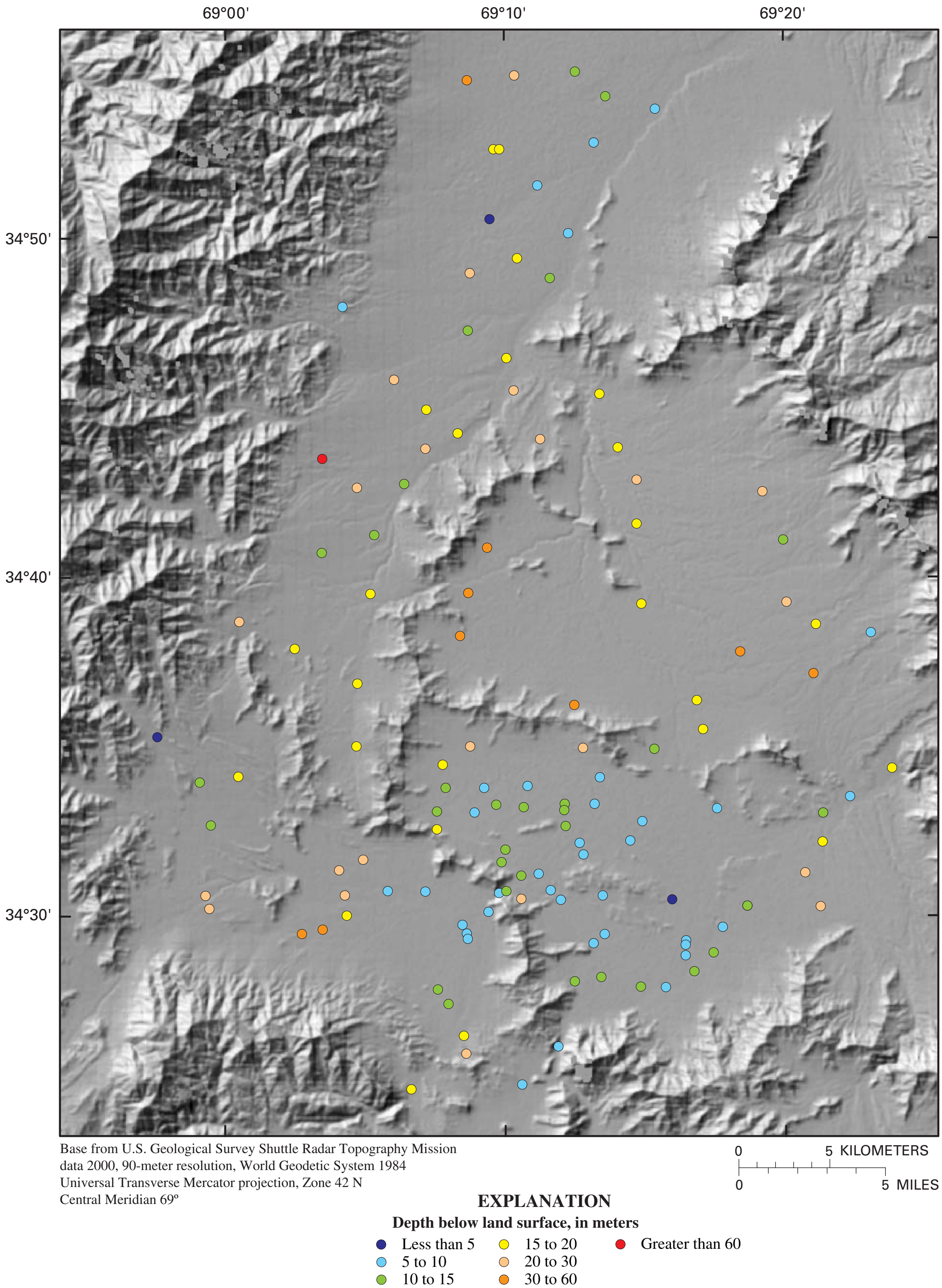


Figure 6. Depth to ground water in the Kabul Basin, Afghanistan, July through November 2004.

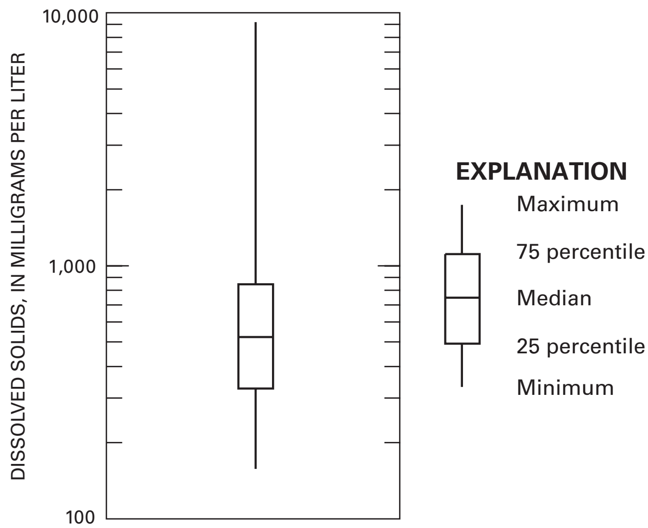


Figure 7. Concentrations of dissolved solids in ground water in the Kabul Basin, Afghanistan, July through November 2004.

Variation in ground-water chemistry from upgradient to downgradient locations in the major subbasins is depicted by radial diagrams in figure 13. The sample from well 20 (fig. 13a), located in the upgradient area of Shomali, has low dissolved solids (181 mg/L) and a distinctly calcium bicarbonate water type. Downgradient in Shomali, in the sample from well 45 (fig. 13b), the dissolved-solids concentration increases to 413 mg/L, and the water type is calcium magnesium bicarbonate with a considerable increase in sodium concentration. These differences in chemical composition are consistent with weathering of calcite, dolomite, biotite, and other common minerals, and perhaps some ion exchange. In Paghman, the situation is similar. The sample from well 100 (fig. 13c), located in the upgradient area of Paghman, has low dissolved solids (199 mg/L) and a distinctly calcium bicarbonate water type. Downgradient in Paghman, in the sample from well 121 (fig. 13d), the dissolved-solids concentration has increased to 465 mg/L, and the water type is calcium magnesium sodium bicarbonate. In Deh Sabz, the sample from upgradient well 7 (fig. 13e) is low in dissolved solids (248 mg/L) and calcium magnesium bicarbonate in water type. Downgradient in this subbasin, in well 37 (fig. 13f), dissolved solids are 521 mg/L, and the water type is mixed with increased concentrations of sodium and sulfate. These changes in chemical composition may be attributable to weathering of rock that may include gypsum.

Ground water within central Kabul is more vulnerable to anthropogenic influence than in other parts of the basin. Even wells in relatively upgradient locations are rather high in dissolved-solids concentration. In the sample from well 174 (fig. 13g), for example, the concentration of dissolved solids is 508 mg/L. The water type of this sample is calcium magnesium bicarbonate, but sodium is also present at higher concentration than in upgradient wells in the other subbasins. Samples from downgradient wells in central Kabul are mixed in water type. As shown in figures 13h through 13j, many of these wells are elevated in sodium, magnesium, and chloride. These differences are likely due to a combination of rock weathering, evaporative concentration, and anthropogenic sources.

Oxidation-Reduction (Redox) Conditions

Based on the samples collected in this study, ground water in the Kabul Basin is generally oxic in nature. Several lines of evidence indicate this condition. Dissolved-oxygen concentration ranges from 0.4 to 16.5 mg/L with only two samples (wells 1 and 111) measuring below 2.0 mg/L; the median value is 7.6 mg/L. While this range is highly oxic, many dissolved-oxygen values measured in this study have considerable uncertainty and likely have a positive bias. Measurements were not made in a sealed, flow-through chamber, and surface aeration was often evident during sampling.

Concentrations of other constituents, however, support the existence of oxic conditions in the aquifer. Iron and manganese are redox sensitive elements, both being much more soluble under reducing conditions. Concentrations of both elements are generally low. Iron concentrations range from 3 μg/L to 1,690 μg/L, but only one of the 108 samples (well 110) has an iron concentration higher than 300 μg/L. Only three other wells (115, 150, and 166) have iron concentrations over 70 μg/L. Manganese concentrations range from 0.1 μg/L to 1,070 μg/L, but only four wells (115, 139, 153, and 156) have values above 40 μg/L.

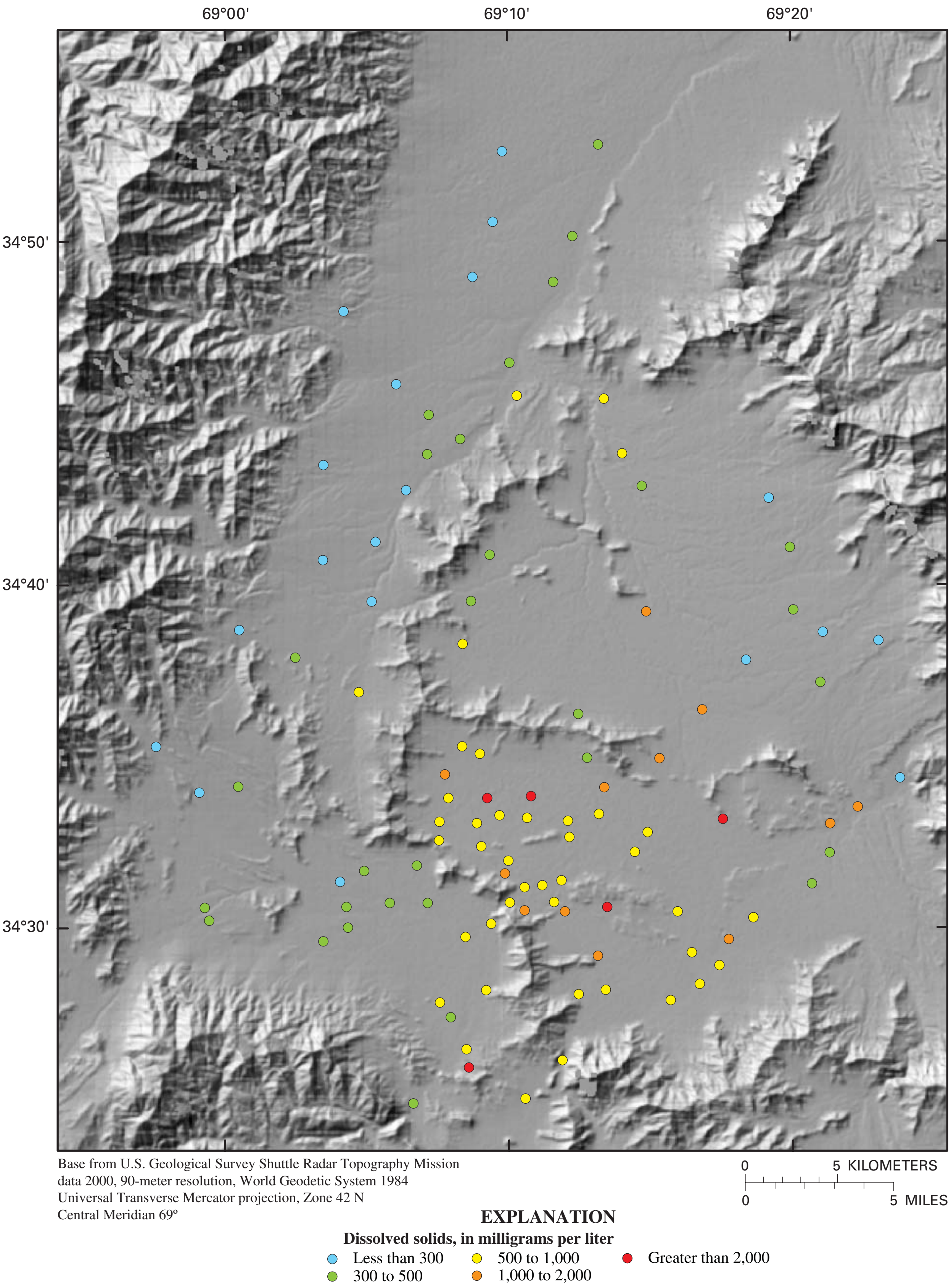


Figure 8. Spatial distribution of concentrations of dissolved solids in ground water in the Kabul Basin, Afghanistan, July through November 2004.

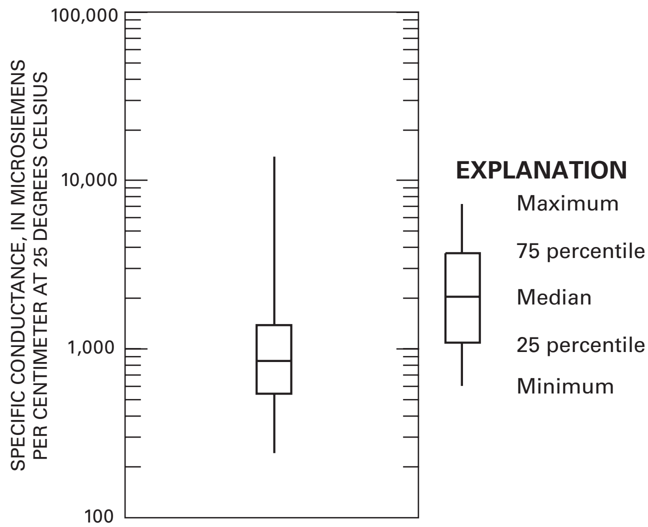


Figure 9. Specific conductance in ground water in the Kabul Basin, Afghanistan, July through November 2004.

A final line of evidence for oxic conditions in Kabul Basin ground water comes from samples from the seven wells (202, 205, 206, 211, 216, 219, and 220) for which nitrate, ammonia, and total nitrogen were determined. In these wells the nitrate concentration ranges from 97 to 106 percent of the total nitrogen value (ratios greater than 100 percent are possible due to analytical variability). All ammonia concentrations are below the detection level of 0.02 mg/L as N. In the samples from 108 wells that were analyzed for nitrite, the nitrite concentration exceeded 0.06 mg/L as N in only two samples. Nitrate is the most oxidized form of nitrogen, and the fact that the nitrogen pool is dominated by this species supports the prevalence of oxic conditions in the aquifer.

Nitrate

Values of nitrate show spatial patterns likely indicative of both agricultural and urban influences (fig. 14). Concentrations in recharge zones upgradient from these influences are generally less than 2 mg/L as N. They increase to 2 to 10 mg/L as N in the important agricultural areas of Shomali. Nitrate concentration is elevated in the urban areas of the basin, where they can exceed the USEPA drinking-water standard of 10 mg/L as N. In 108 wells where nitrate was measured, this standard is exceeded at 14 sites, or 13 percent of all samples. This percentage is slightly higher than the 10.8 percent rate of exceedances observed by Banks and Soldal (2002). The highest observed concentration of nitrate is 144 mg/L as N in well 132 located in central Kabul. Elevated nitrate in this area may be associated with the presence of a local cemetery. A boxplot of nitrate concentration appears in figure 15. For all sites, the median concentration is 3.7 mg/L as N. The mean concentration for wells located in municipal Kabul City (see appendix) is 8.8 mg/L as N. This value is comparable to the mean of 9.4 mg/L as N reported by Banks and Soldal (2002).

The nitrate values in figures 14 and 15 were generated by laboratory analysis using the cadmium reduction method (Fishman, 1993). These values correspond well with concentration ranges estimated from field test strips. As shown in table 4, in about 82 percent of all cases, the field estimate brackets the analytical value; in most of the remaining cases, the analytical value is only slightly different from the field estimate.

Table 4. Comparison of results of nitrate analysis by field test strips with laboratory analytical values.

[Concentrations in milligrams per liter as N]

Field test strip range	Number of analyses	Number of values in agreement	Percentage in agreement	Concentration of greatest outlier
< 5	84	71	84.5	15.6
5 - 10	12	9	75.0	11.6
10 - 20	5	3	60.0	29.5
> 20	4	3	75.0	16.6
All	105	86	81.9	

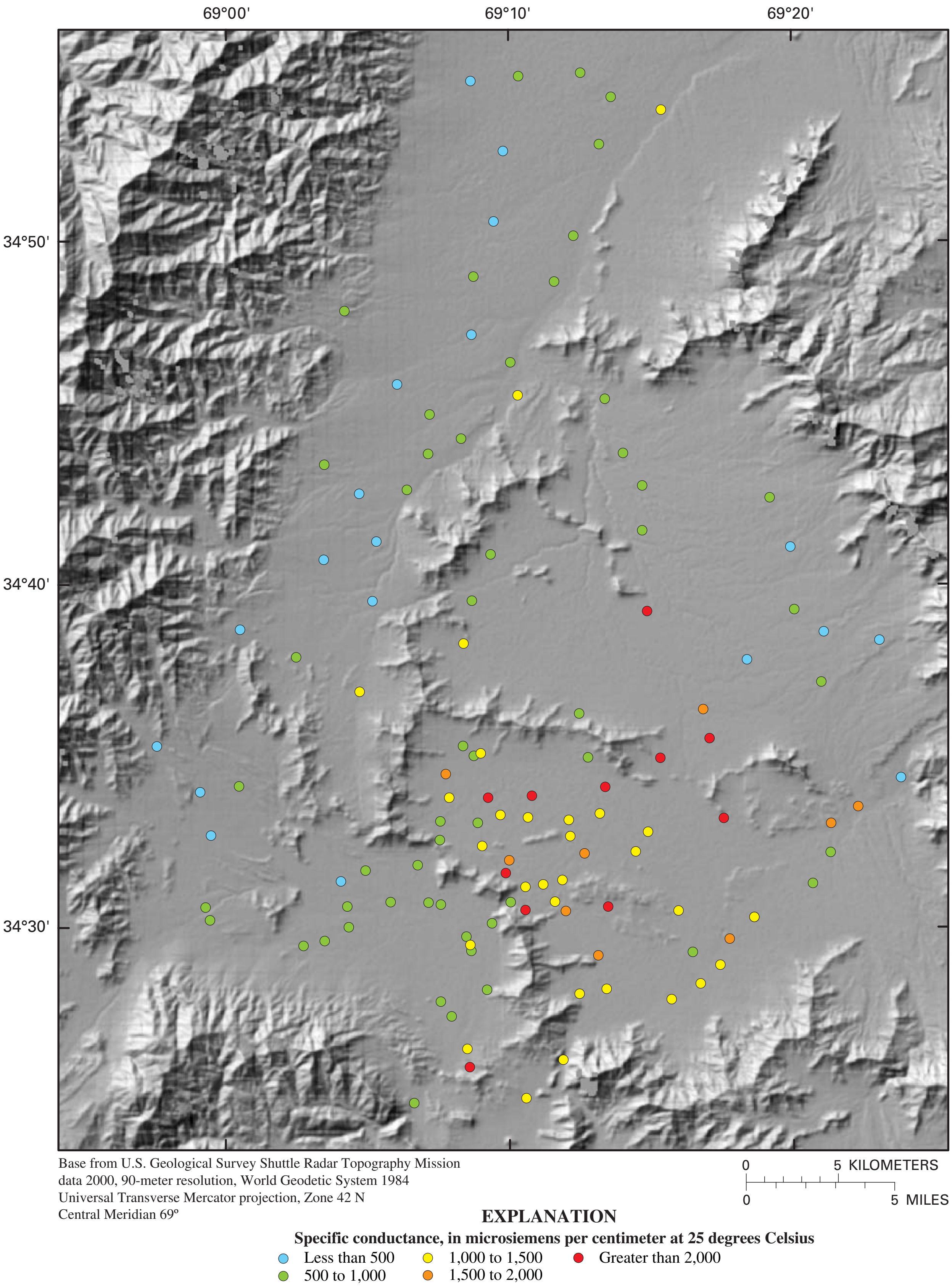


Figure 10. Spatial distribution of specific conductance in ground water in the Kabul Basin, Afghanistan, July through November 2004.

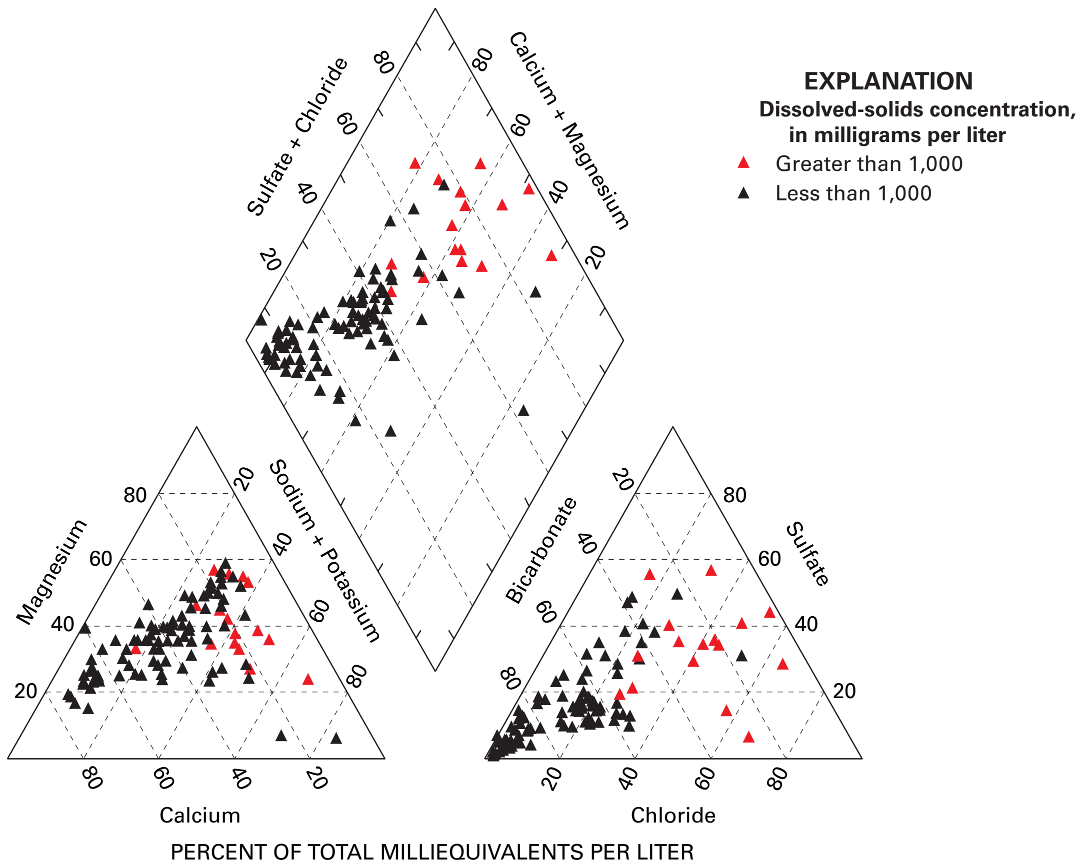


Figure 11. Piper diagram of samples from ground water in the Kabul Basin, Afghanistan, July through November 2004.

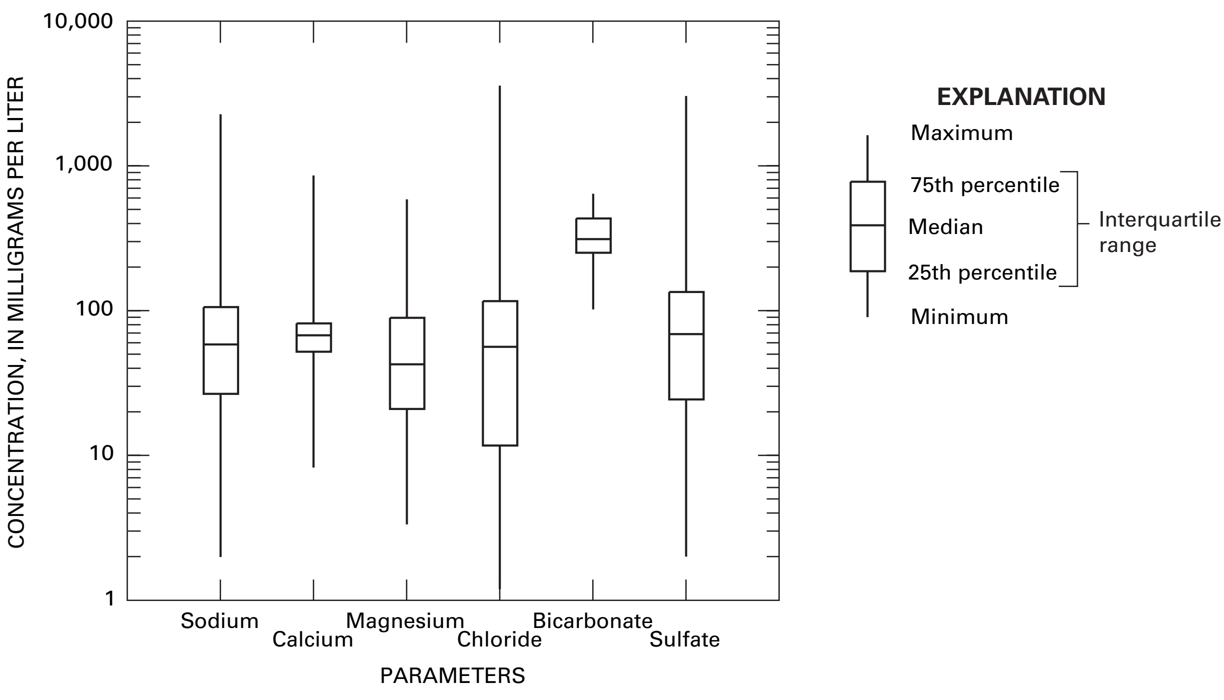


Figure 12. Boxplot of major ion concentrations in ground water in the Kabul Basin, Afghanistan, July through November 2004.

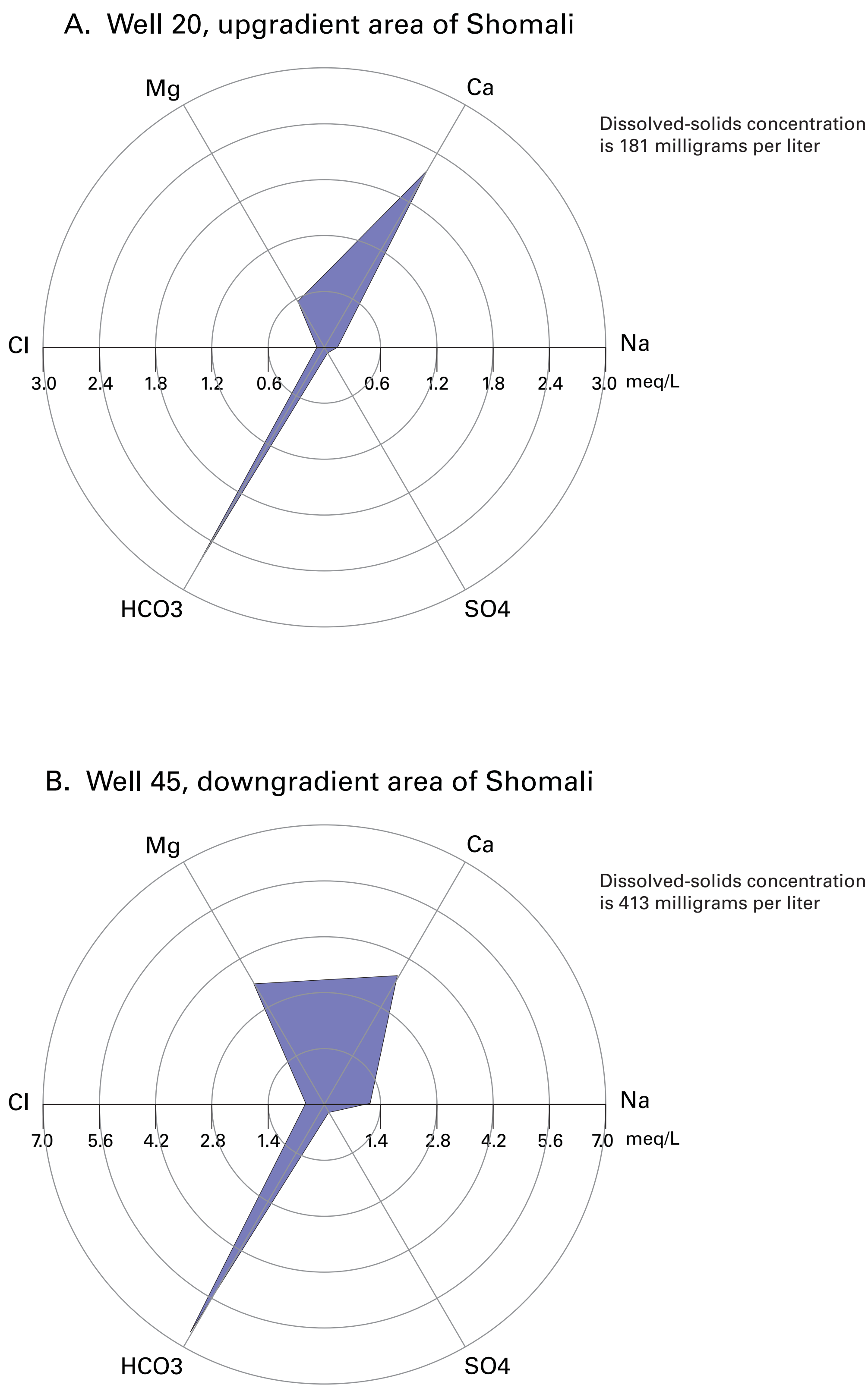
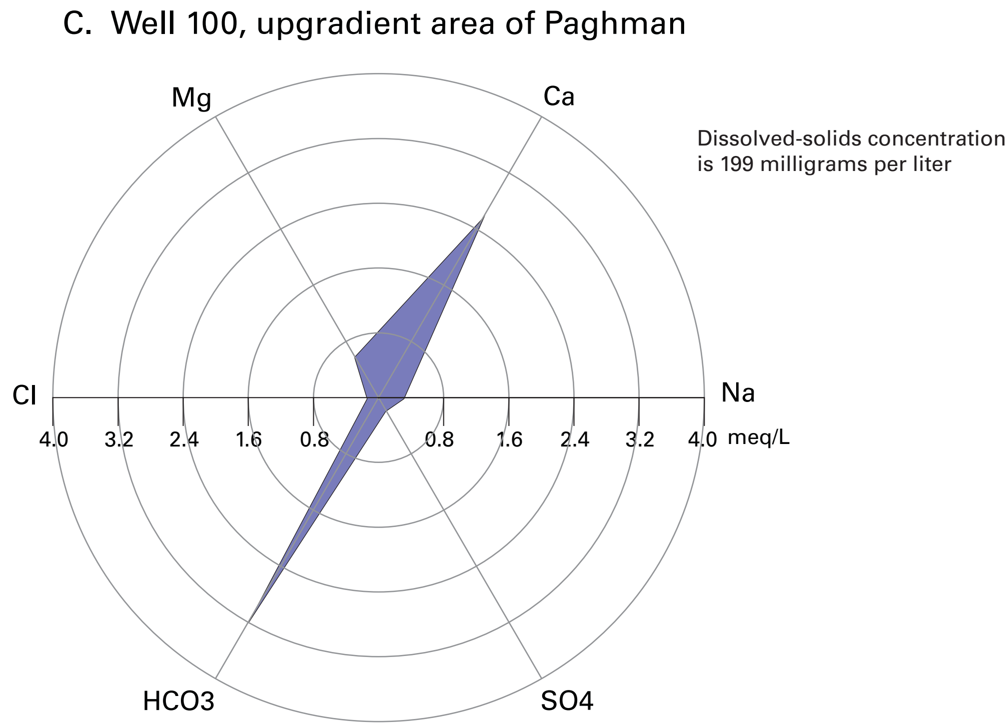


Figure 13. Radial plots of major ion chemistry in ground water in the Kabul Basin, Afghanistan, October through November 2004.



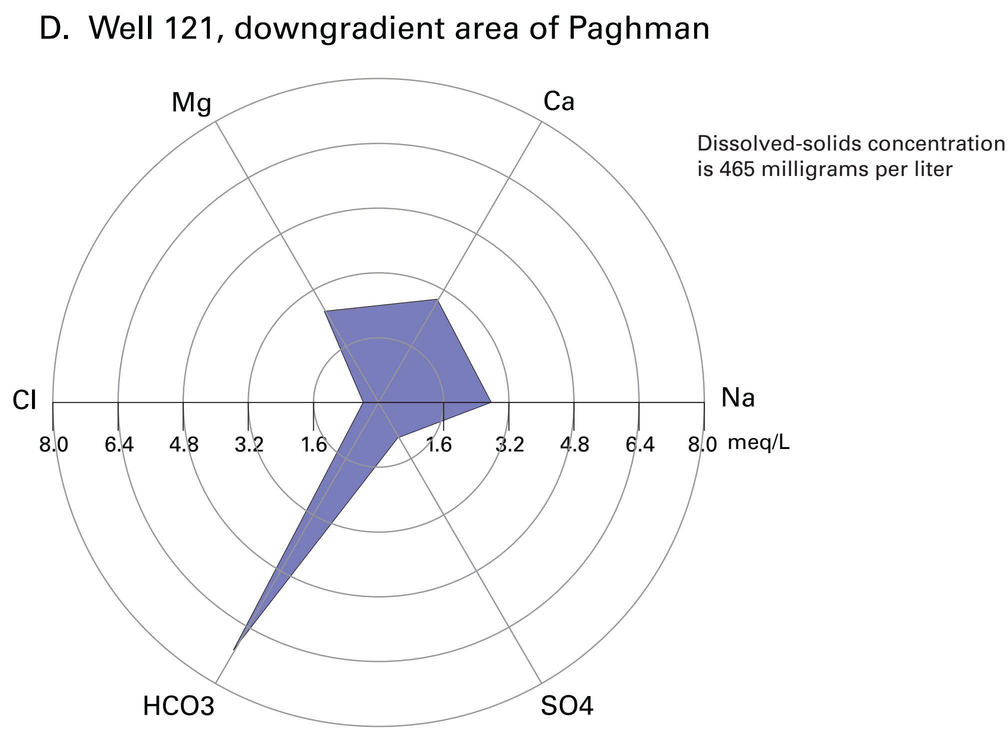


Figure 13. Radial plots of major ion chemistry in ground water in the Kabul Basin, Afghanistan, October through November 2004.—Continued

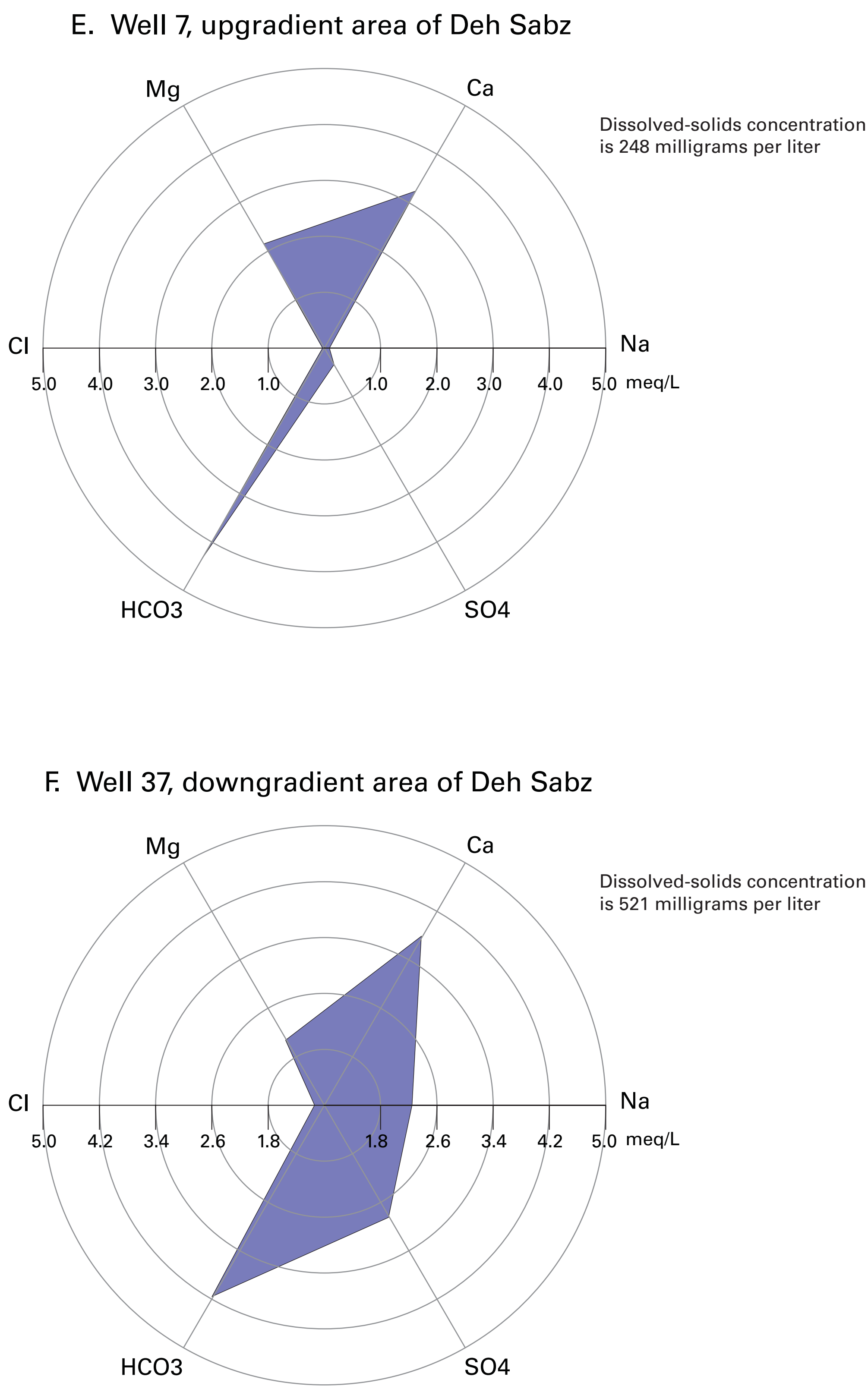


Figure 13. Radial plots of major ion chemistry in ground water in the Kabul Basin, Afghanistan, October through November 2004.—Continued

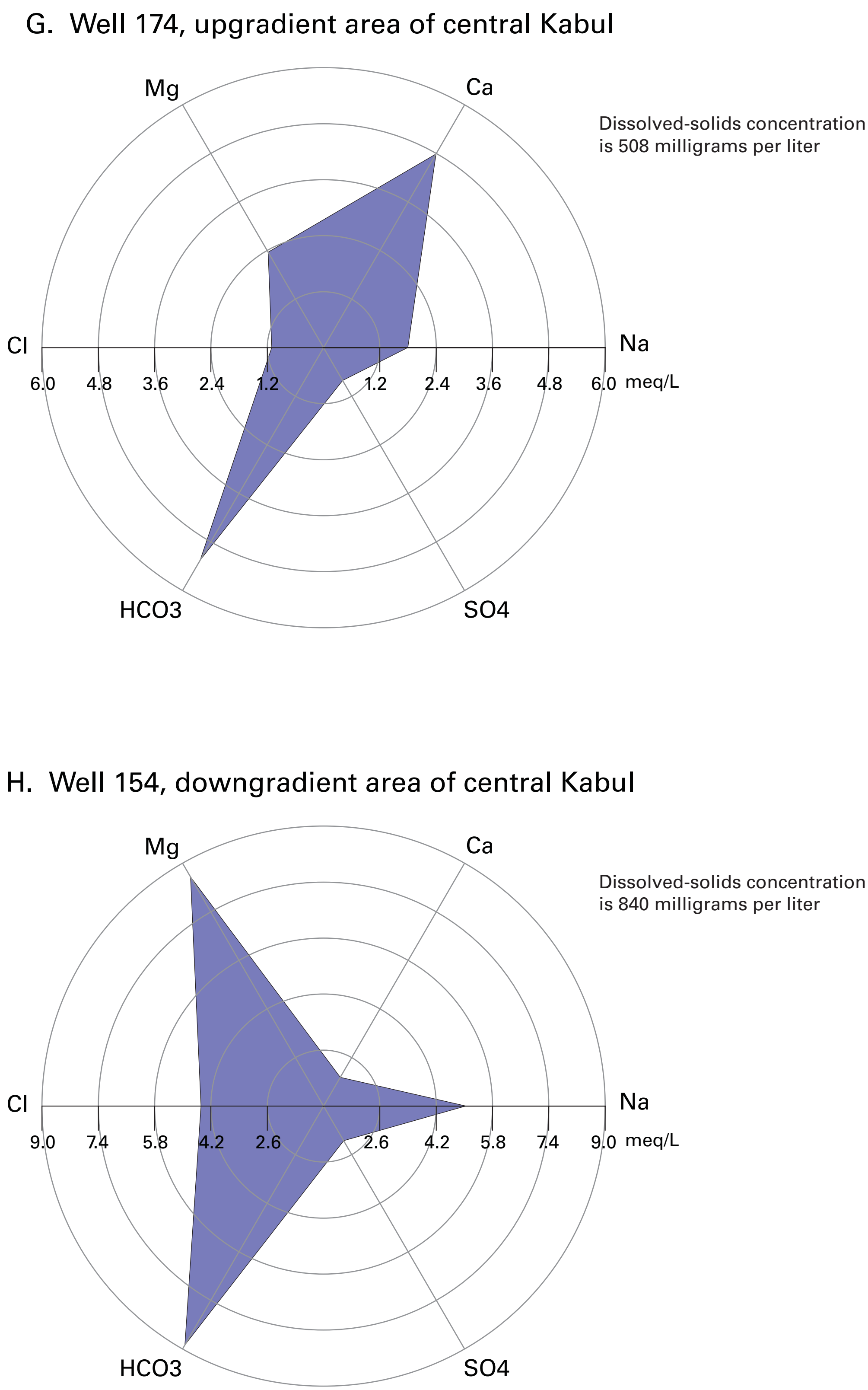
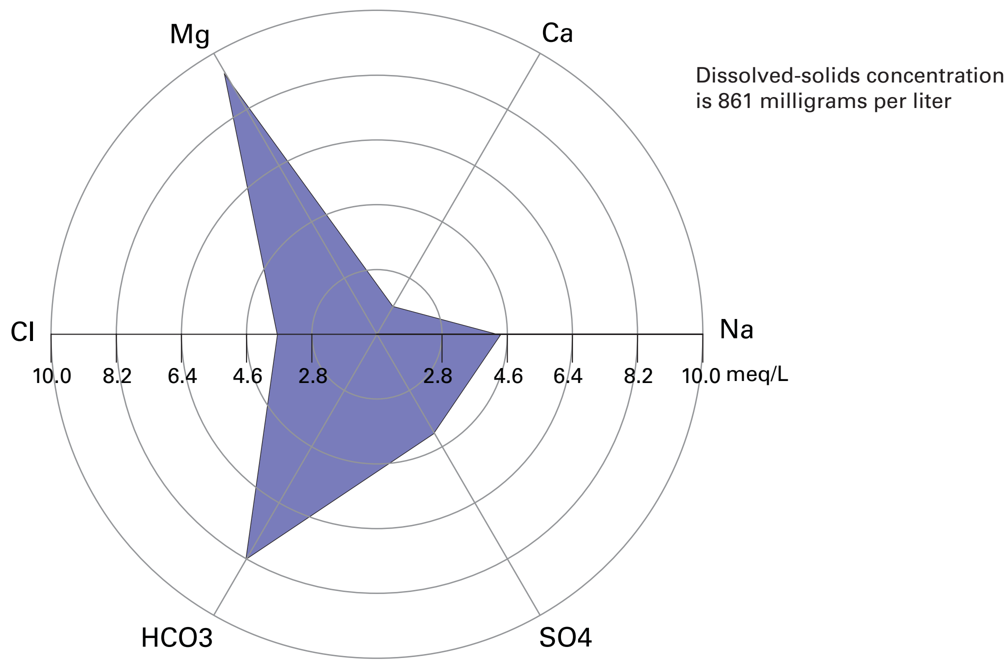


Figure 13. Radial plots of major ion chemistry in ground water in the Kabul Basin, Afghanistan, October through November 2004.—Continued

I. Well 159, downgradient area of central Kabul



J. Well 160, downgradient area of central Kabul

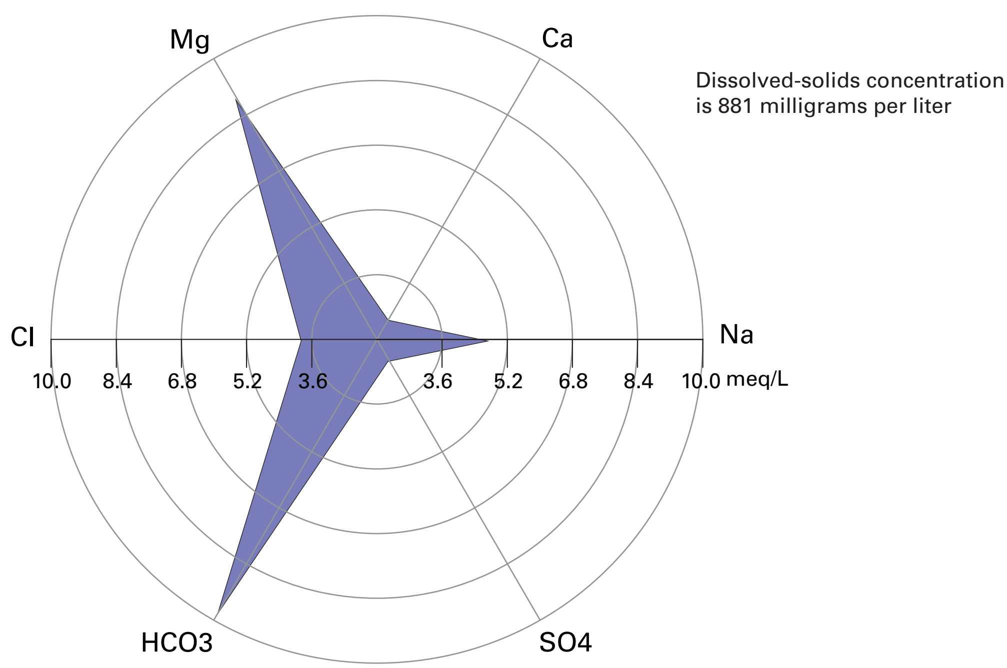


Figure 13. Radial plots of major ion chemistry in ground water in the Kabul Basin, Afghanistan, October through November 2004.—Continued

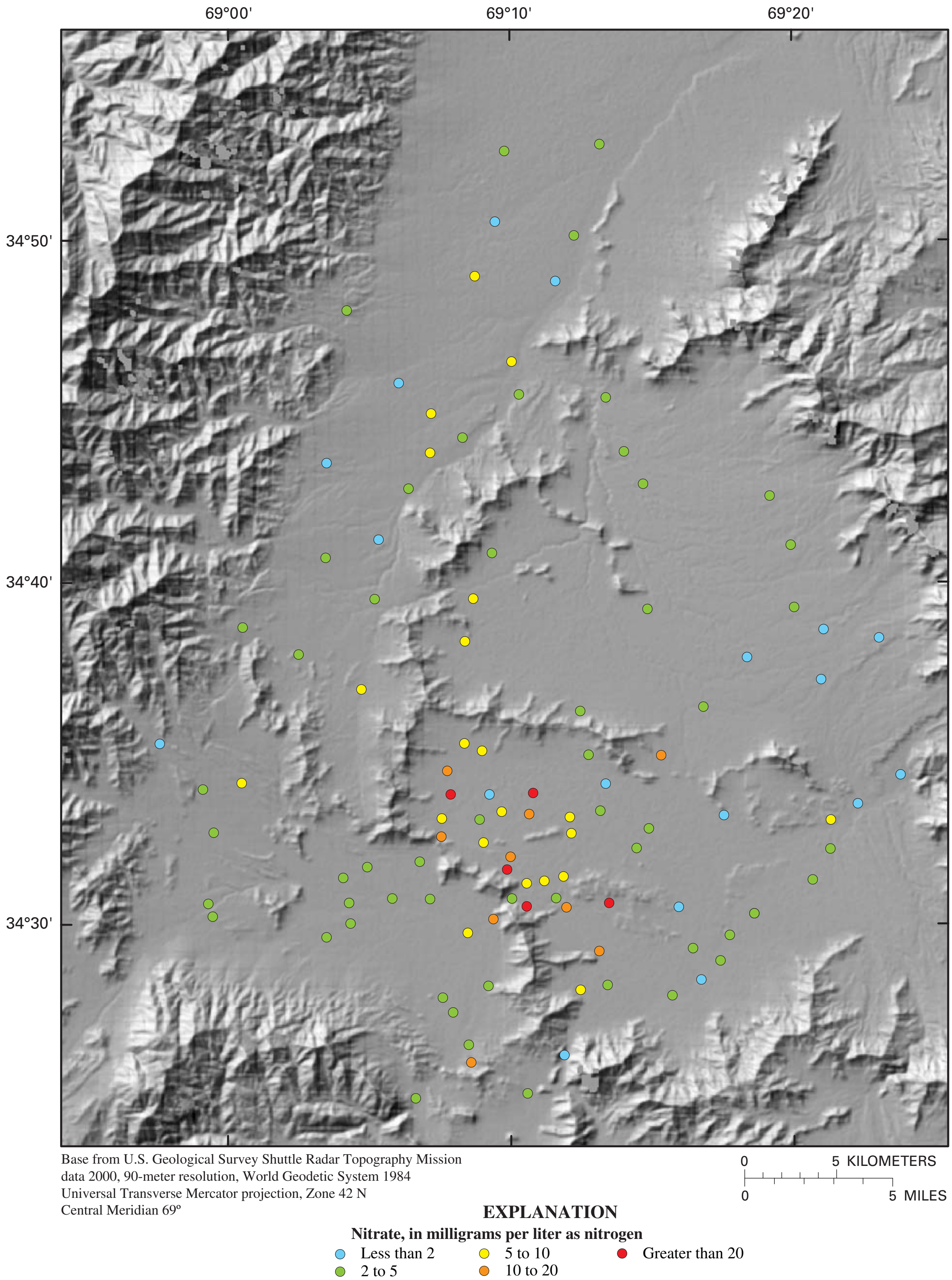


Figure 14. Spatial distribution of nitrate concentration in ground water in the Kabul Basin, Afghanistan, July through November 2004.

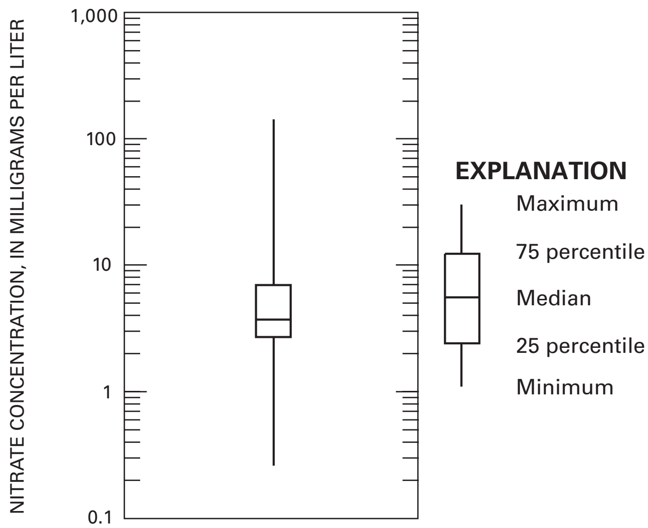


Figure 15. Nitrate concentration in ground water in the Kabul Basin, Afghanistan, July through November 2004.

Bacteria

The distribution of bacteria in the basin shows no particular spatial pattern (fig. 16). *E. coli* was detected in 24 of 108 samples. In only six samples (wells 12, 20, 31, 111, 139, and 177) did the enumeration exceed 10 col/100 mL. The highest value of >200 col/100 mL was observed in the sample from well 111 in west Kabul. The presence of cultural *E. coli* in these ground waters is a clear indication of fecal contamination. This condition reflects the general lack of wastewater treatment throughout the basin.

Sodium Adsorption Ratio

The sodium adsorption ratio (SAR) is an important measure of the tendency of irrigation water to cause structural damage to soils. SAR is defined as

$$SAR = \frac{Na}{\left(\frac{Ca + Mg}{2}\right)^{0.5}}$$

where concentrations of Na, Ca, and Mg are given in milliequivalents per liter. Values of SAR in excess of 4 are considered potentially problematic (U.S. Salinity Laboratory Staff, 1954). SAR is 4 or greater in 10 of 108 samples; the highest value of 20.8 occurs in the sample from well 153. The distribution of SAR in ground water from the Kabul Basin is depicted in figures 17 and 18. SAR levels are below problematic thresholds in the important agricultural areas of Shomali. In central Kabul, however, where small agricultural plots are common, there is cause for concern in some isolated areas.

Boron

Another parameter that is important for use of ground water in irrigation is boron concentration. Concentrations of boron exceeding 1,000 µg/L can be problematic for sensitive crops like grapes and apples, while boron concentrations in excess of 3,000 µg/L are detrimental to more tolerant plants like date palms, lettuce, and turnips (U.S. Salinity Laboratory Staff, 1954). Patterns in concentrations of boron are shown in figures 19 and 20. Boron concentration exceeds 1,000 µg/L in 31 of 108 wells sampled in the basin; in three wells (15, 153, and 177) the concentration is greater than 3,000 µg/L. The highest observed concentration is 7,600 µg/L in well 153 in central Kabul.

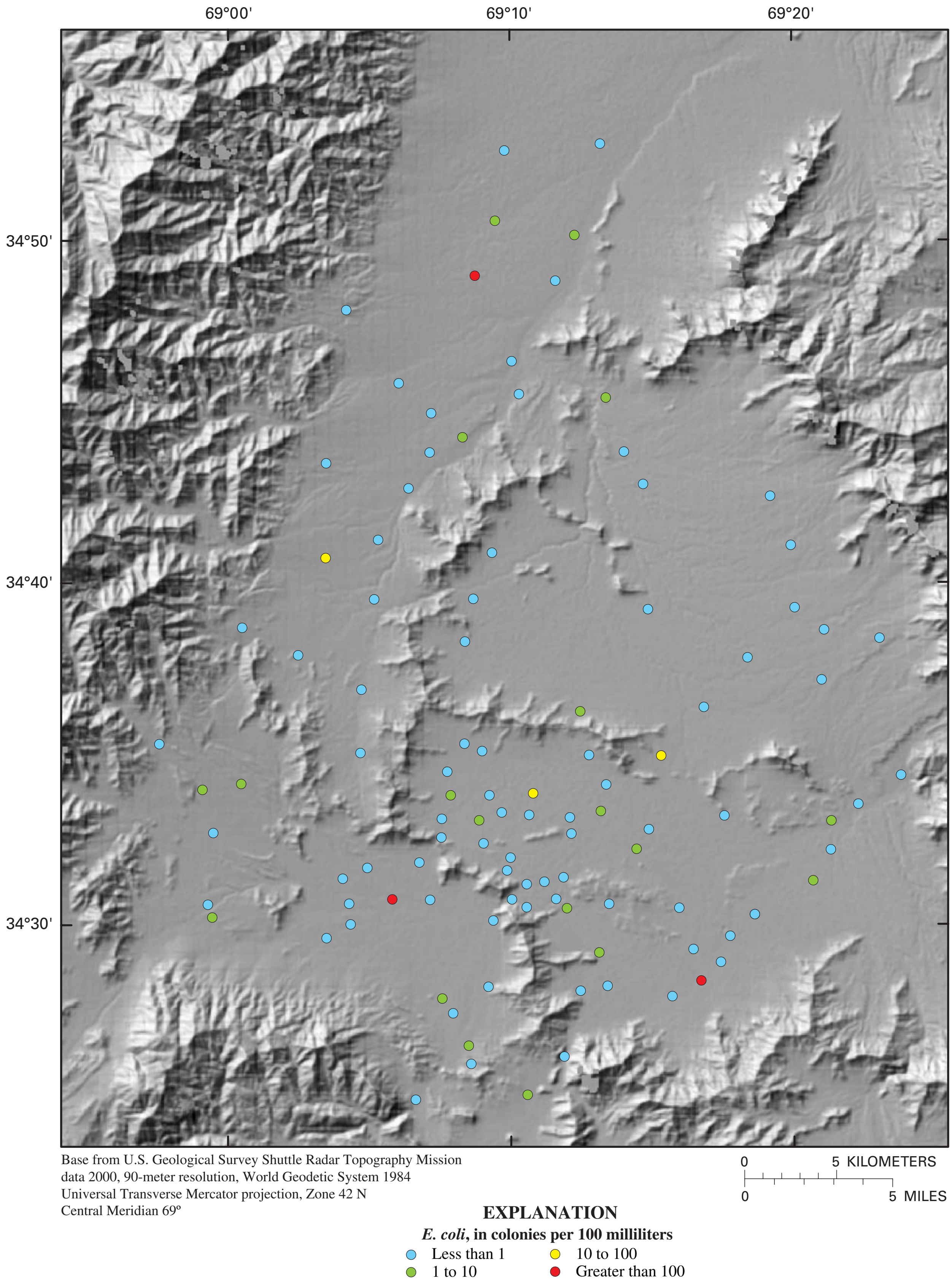


Figure 16. Spatial distribution of colonies of *E. coli* in ground water in the Kabul Basin, Afghanistan, July through November 2004.

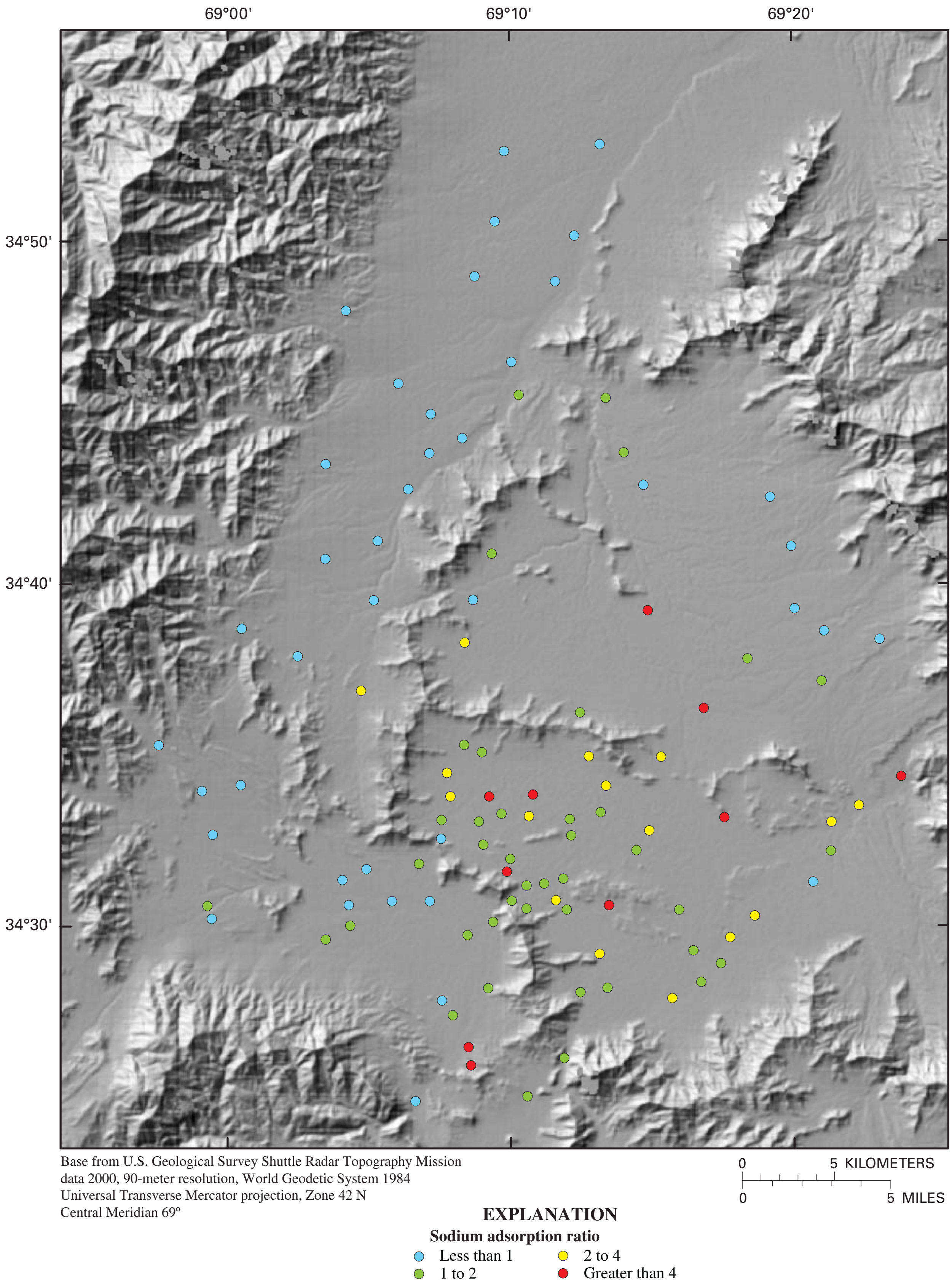


Figure 17. Spatial distribution of sodium adsorption ratio in ground water in the Kabul Basin, Afghanistan, July through November 2004.

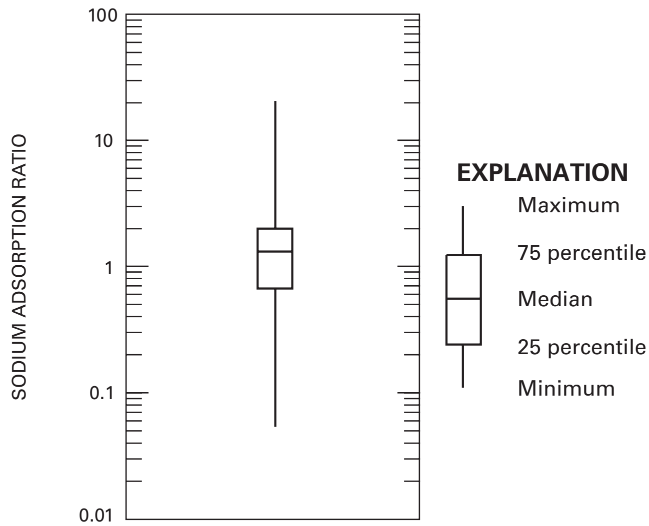


Figure 18. Sodium adsorption ratio in ground water in the Kabul Basin, Afghanistan, July through November 2004.

Further Considerations for Ground-Water Use as Public Drinking Water

Table 5 lists 24 constituents for which USEPA has issued drinking-water standards, health advisories, or secondary drinking-water regulations. Although these thresholds of concern have no legal weight in Afghanistan, a comparison of these values with concentrations measured in ground water in the Kabul Basin provides a general measure of the suitability of ground water as a healthy source of public water supply. At least one of the USEPA thresholds of concern was exceeded in at least one well for 14 constituents. Over 10 percent of the samples collected in this study had exceedances for dissolved solids, boron, *E. coli*, sulfate, nitrate, or chloride. Boxplots of selected constituents are shown in figures 21 and 22.

Suggestions for Further Work

As Afghanistan emerges from years of conflict, as institutional capacities rejuvenate and grow, and as the need for wise water-management decisions continues, adequate data and a fuller understanding of the ground-water resource in the Kabul Basin will be imperative. The work described in this report represents only a modest beginning in what will be a long-term data collection and interpretive effort.

Major questions regarding ground water in the Kabul Basin remain unanswered:

- What is the sustainable yield of ground water in various parts of the Kabul Basin?
- How will ground-water resources be affected by continuing drought conditions and by an eventual return to more normal climatic patterns?
- How deep are the alluvial systems?
- What is the distribution of hydraulic head in the vertical dimension?
- Are there major confining layers and, if so, what is their lateral extent?
- Is deeper (>200 m) ground water of suitable quality for domestic, agricultural, or industrial use?
- What are patterns of deep regional ground-water flow?
- What are the hydraulic properties of aquifer materials in the basin?

Answers to these questions will become available only after further investigations. These investigations could include:

- Establishment of a ground-water network with wells of known construction from inert materials, well-sealed at the surface, nested in the vertical dimension and with good three-dimensional coverage of the basin, and with secure long-term access
- Regular monitoring of these wells, with monthly measurement of water levels and quarterly sampling for water quality
- More intensive data collection in alluvial wells, including continuous water-level measurements to define interactions between ground water and surface water over the seasonal hydrograph
- Better structural characterization and an understanding of aquifer heterogeneity in the basin using geophysical tools and geologic mapping
- Construction of a ground-water flow model to integrate all hydrogeologic data and understanding within a quantitative framework that can be used to explore scenarios for management and development of the ground-water resource

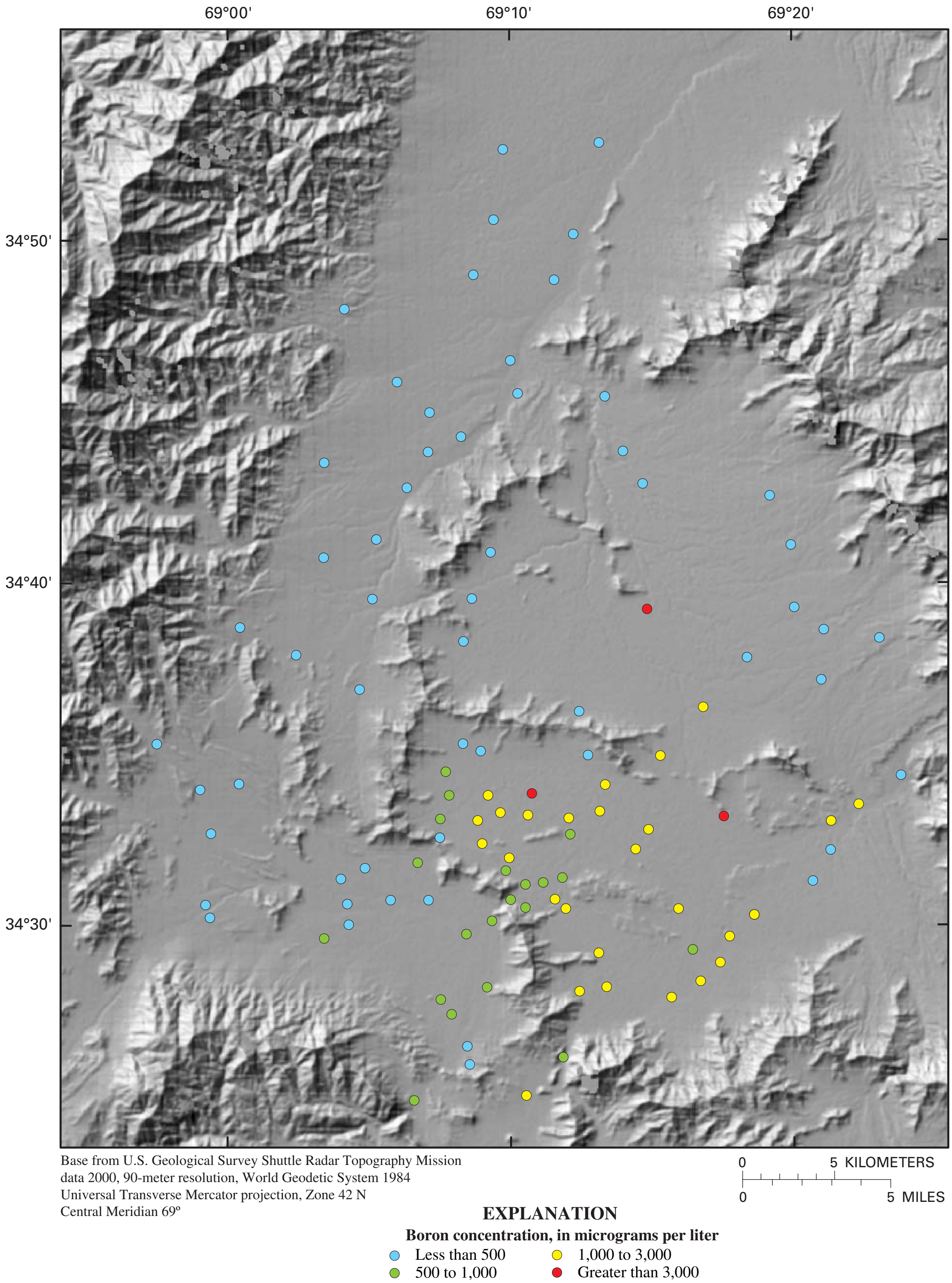


Figure 19. Spatial distribution of boron concentration in ground water in the Kabul Basin, Afghanistan, July through November 2004.

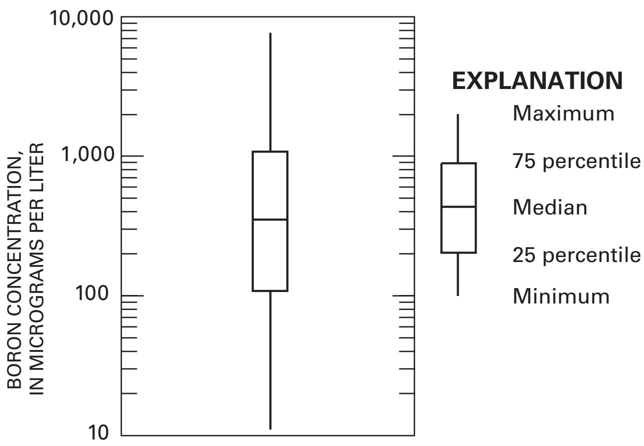


Figure 20. Boron concentration in ground water in the Kabul Basin, Afghanistan, July through November 2004.

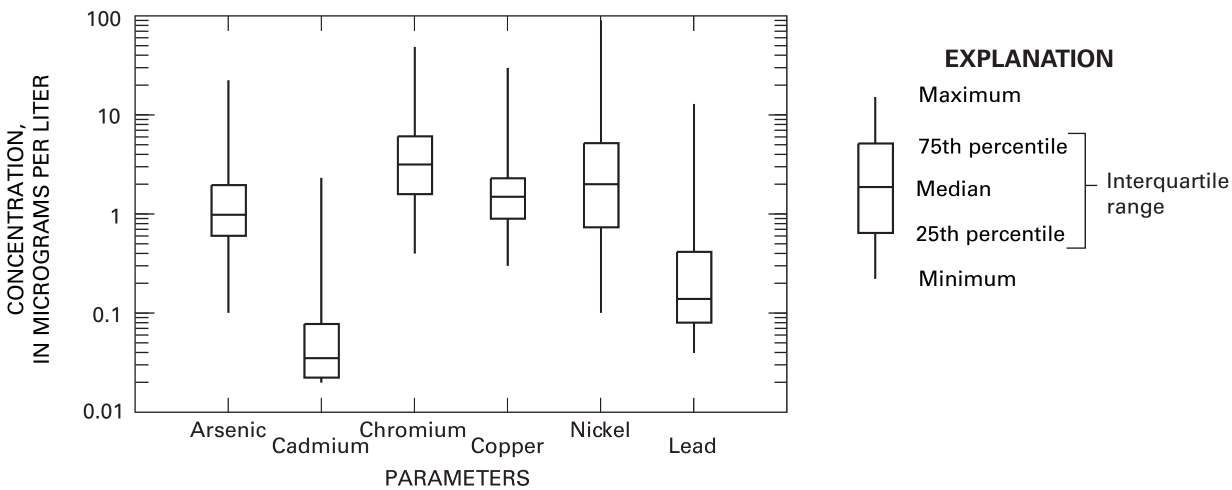


Figure 21. Boxplots of arsenic, cadmium, chromium, copper, nickel, and lead in ground water in the Kabul Basin, Afghanistan, July through November 2004.

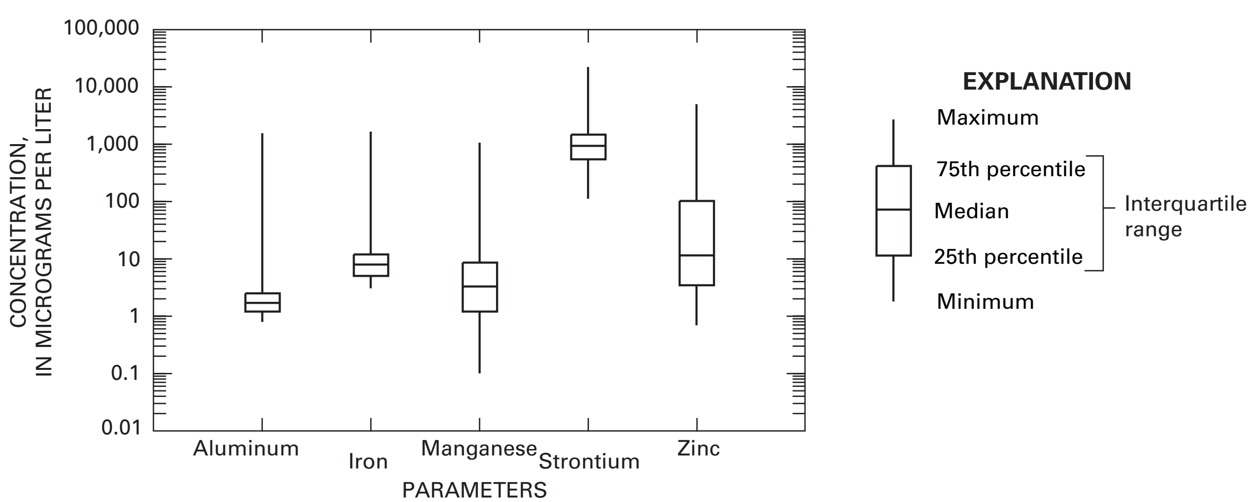


Figure 22. Boxplots of aluminum, iron, manganese, strontium, and zinc in ground water in the Kabul Basin, Afghanistan, July through November 2004.

Table 5. Exceedances of USEPA drinking-water standards, health advisories, and secondary drinking-water regulations in ground-water samples collected in the Kabul Basin, Afghanistan, July to November 2004.

[µg/L, micrograms per liter; col/100 mL, colonies per 100 milliliters; mg/L, milligrams per liter]

Constituent	Standard	Number of samples	Number of exceedances	Percentage of exceedances	Highest value
Drinking-water standards[1]					
Arsenic (µg/L)	10	108	2	1.9	22.7
Barium (µg/L)	2,000	108	0	0.0	257
Beryllium (µg/L)	4	108	0	0.0	0.05
Cadmium (µg/L)	5	108	0	0.0	2.38
Chromium (µg/L)	100	108	0	0.0	49
Copper (µg/L)	1,300	108	0	0.0	30.6
E. coli (col/100 mL)	<1	108	24	22.2	>200
Fluoride (mg/L)	4	108	0	0.0	1.32
Nitrate (mg/L as N)	10	108	14	13.0	144
Lead (µg/L)	15	108	0	0.0	13.1
Selenium (µg/L)	50	108	1	0.9	91.1
Thallium (µg/L)	2	108	0	0.0	<0.12
Health advisories[1]					
Barium (µg/L)	2,000	108	0	0.0	257
Boron (µg/L)	600	108	48	44.4	7,600
Molybdenum (µg/L)	40	108	1	0.9	42.5
Nickel (µg/L)	100	108	0	0.0	88.7
Silver (µg/L)	100	108	0	0.0	0.53
Strontium (µg/L)	4,000	108	5	4.6	22,300
Zinc (µg/L)	2,000	108	3	2.8	5,090
Secondary drinking-water regulations[1]					
Aluminum (µg/L)	50	108	2	1.9	1,570
Chloride (mg/L)	250	104	11	10.6	4,190
Copper (µg/L)	1,000	108	0	0.0	30.6
Dissolved solids (mg/L)	500	107	58	54.2	9,350
Fluoride (mg/L)	2	108	0	0.0	1.32
Iron (µg/L)	300	108	1	0.9	1,690
Manganese (µg/L)	50	108	4	3.7	1,070
Silver (µg/L)	100	108	0	0.0	0.53
Sulfate (mg/L)	250	104	14	13.5	3,030
Zinc (µg/L)	5,000	108	1	0.9	5,090

[1]U.S. Environmental Protection Agency (2004).

Summary

The U.S. Geological Survey has been working with hydrologic engineers at the Afghanistan Geological Survey to provide training and equipment and to apply these tools to build an inventory of water wells in the Kabul Basin of Afghanistan. Training and equipment are being provided in computer science, data base management, geographic information systems, geographic positioning systems, field hydrogeology, and water quality. An inventory of 148 wells now includes information on well location, depth, and access. Water-level and water-quality measurements have been made at most of these wells. A water-level elevation map has been constructed, and general directions of ground-water flow have been defined.

Afghanistan lies along the great tectonic upheaval that has produced the world's highest mountain ranges: the Himalaya, Karakoram, Pamirs, and the Hindu Kush. In the Kabul area orogeny has been accompanied by a complex sequence of faulting. Deep grabens in crystalline rocks have formed and have filled with hundreds of meters of alluvial, colluvial, and lacustrine deposits. Ground-water flow in the Kabul Basin is primarily through saturated alluvium and other basin-fill sediments. The water-table surface generally mirrors topography, and ground water generally flows in the directions of surface-water discharge.

The quality of ground water in the Kabul Basin varies widely. In some areas ground-water quality is excellent, with low concentrations of dissolved solids (less than 500 mg/L) and no problematic constituents. In other areas, however, high concentrations of dissolved solids and the presence of some constituents at concentrations deemed harmful to humans and crops render untreated ground water marginal or unsuitable for public supply and/or agricultural use. Of particular concern are elevated concentrations of nitrate, boron, and dissolved solids, and an indication of fecal contamination in some parts of the basin. Nitrate concentration exceeds the USEPA drinking-water standard of 10 mg/L as N in 14 of 108 samples. Boron concentration exceeds 1,000 µg/L in 31 of 108 samples. The concentration of dissolved solids exceeds 500 mg/L in 58 of 107 samples. *E. coli* is present in 24 of 108 samples.

As Afghanistan emerges from years of conflict, as institutional capacities rejuvenate and grow, and as the need for wise water-management decisions continues, adequate data and a fuller understanding of the ground-water resource in the Kabul Basin will be imperative. The work described in this report represents only a modest beginning in what will be a long-term data collection and interpretive effort. This effort could include construction of a network of wells for periodic measurement of water levels and water quality. Geophysical tools could be applied to develop a better understanding of how geologic structure controls ground-water flow in the basin. Finally, all aspects of the hydrologic work eventually could be expressed in a ground-water flow model that can be used to explore scenarios for development of the ground-water resource.

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