Chapter 11
Sustainability of Water Supply at Military Installations, Kabul Basin, Afghanistan[1]

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Abstract

The Kabul Basin, including the city of Kabul, Afghanistan, is host to several military installations of Afghanistan, the United States, and other nations that depend on groundwater resources for water supply. These installations are within or close to the city of Kabul. Groundwater also is the potable supply for the approximately 4 million residents of Kabul. The sustainability of water resources in the Kabul Basin is a concern to military operations and Afghan water-resource managers owing to increased water demands from a growing population and potential mining activities. This study illustrates the use of chemical and isotopic analysis, groundwater flow modeling, and hydrogeologic investigations to assess the sustainability of groundwater resources in the Kabul Basin.

Water supplies for military installations in the southern Kabul Basin were found to be subject to sustainability concerns, such as the potential drying of shallow-water supply wells as a result of declining water levels. Model simulations indicate that new withdrawals from deep aquifers may have less of an impact on surrounding community water supply wells than increased withdrawals from near-surface aquifers. Higher rates of recharge in the northern Kabul Basin indicate that military installations in that part of the basin may have fewer issues with long-term water sustainability. Simulations of groundwater withdrawals may be used to evaluate different withdrawal scenarios in an effort to manage water resources in a sustainable manner in the Kabul Basin.

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11.1 Introduction

Military installations in Afghanistan currently (2012) rely on groundwater for a significant portion of their water supply (Gellasch 2012). The Kabul Basin is host to several military installations of Afghanistan, the United States, and other nations, including the Bagram Airfield in the north and the International Security Assistance Force (ISAF) compound in the city of Kabul. The sustainability of the region's principal aquifer systems is largely uncharacterized, and an improved understanding of the water resources of the region can aid in the effective management of water resources (Uhl, 2006). The city of Kabul (fig. 11.1), with a population of approximately 4 million people, also depends solely on groundwater for drinking water supplies. The sustainability of water resources in the Kabul Basin is of concern to military planners and Afghan water-resource managers owing to the region's water needs for a growing population and for potential mining activities.

Investigations by the United States Department of Defense Task Force for Business and Stability Operations (TFBSO), the U.S. Geological Survey (USGS), and the Afghanistan Geological Survey (AGS) indicate that copper deposits immediately south of the Kabul Basin have the potential to provide considerable economic opportunity to Afghanistan (Peters et al. 2011). Understanding the water resources of the Kabul Basin is necessary for the military installations in the Kabul Basin but also for the social and economic sustainability of Kabul and Afghanistan. Collaboration between the USGS, TFBSO, and AGS and scientific investigations conducted under agreements with the United States Agency for International Development (USAID) have led to improved understanding and management of water resources in the Kabul Basin. This chapter examines the methods of investigation, particularly chemical and isotopic analysis of water resources, and simulations of groundwater flow that have contributed to the assessment of water-resources sustainability in the region.

11.1.1 Site Descriptions

For this study, the Kabul Basin is defined as the drainage area to the valley holding the city of Kabul, which extends about 40 km north of the city. The basin is bordered to the west by the Paghman Mountains and to the east by the Kohe Safi Mountains (fig. 11.1). This area excludes the drainages outside the valley. Subbasins of the Kabul Basin are formed by interbasin ridges and river drainage divides (fig. 11.1). Several military installations within and adjacent to the city of Kabul are in subbasins that compose the southern Kabul Basin; the Bagram Airfield is in the northern Kabul Basin. An economically significant copper deposit is immediately south of the Kabul Basin (Peters et al. 2011).

The primary aquifer in the Kabul Basin is a surficial sedimentary aquifer in the bottom of the basin (fig. 11.2). The underlying semiconsolidated sediment is a less used aquifer, and the sedimentary and fractured metamorphic and crystalline bedrock of the surrounding mountains and interbasin ridges are the least used aquifers in the Kabul Basin. Alluvial fans have developed on the flanks of the mountains surrounding the subbasins and on the interbasin ridges. Deposits in the central plains include alluvium and loess sediment, typically less than 80 m thick, that overlie semiconsolidated conglomerate sediment up to 1,000 m thick (fig. 11.2). Studies that have investigated aquifers in the southern Kabul Basin include those by Myslil et al. (1982), Japan International Corporation Agency (2007), Lashkaripour and Hussaini (2008), and Houben et al (2009).
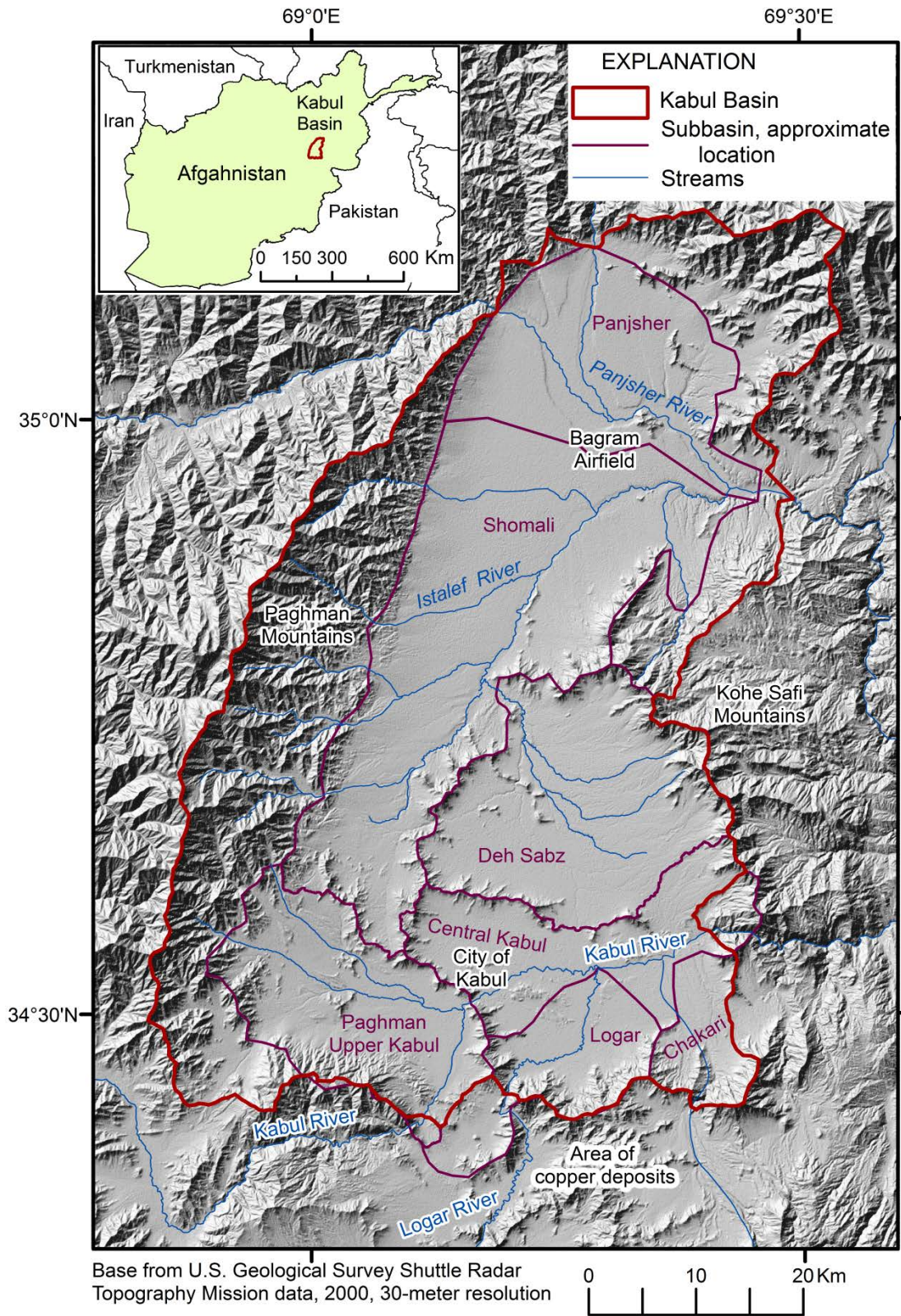
Figure 11.1. The Kabul Basin, Afghanistan, with major geographic features and approximate subbasins.

EXPLANATION

Sediments
- Fan alluvium
- Loess
- Alluvium
- River channel alluvium

Bedrock
- Sandstones
- Limestones
- Metamorphics
- Intrusives
- –··– Kabul Basin
- – — Fault, approximately located

A

69°00'E   69°30'E

35°00'N

Line of geologic section

34°30'N

0   10   20 KILOMETERS
0   10   20 MILES

B

Precipitation

Melting glacier

Evapotranspiration

River

Primary aquifer

Water table

Secondary aquifer

Thrust fault zone

Not to scale

Geology modified from Bohannon and Turner 2007; and Lindsay et al. 2005

EXPLANATION

Sediments
- Fan alluvium
- Loess and alluvium
- Conglomerate
- Alluvium

Bedrock
- Sandstones
- Metamorphics
- Limestones
- Intrusives
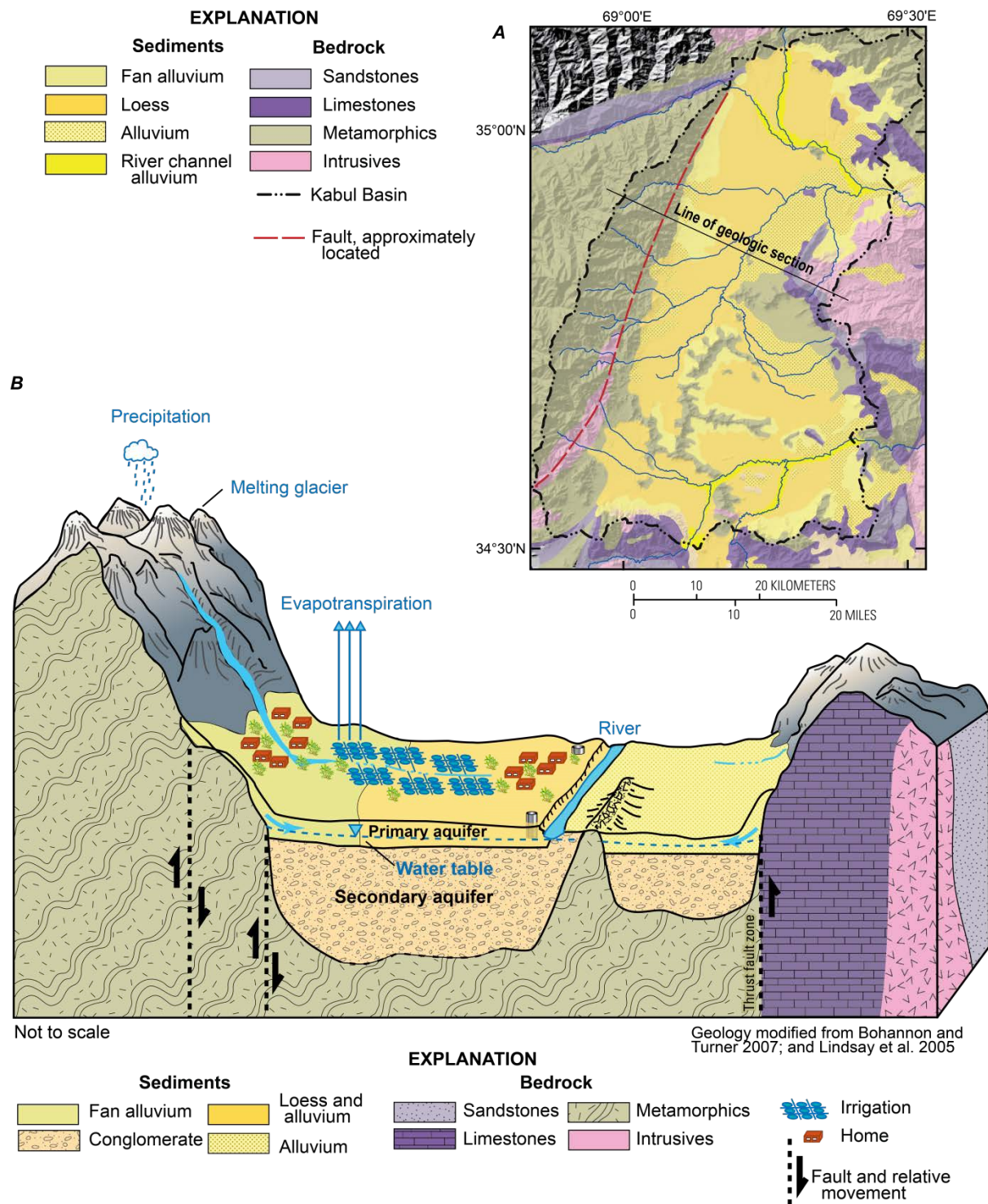- Irrigation
- Home
- Fault and relative movement

Figure 11.2.   Generalized surficial geology and cross section and schematic diagram of the Kabul Basin, Afghanistan.

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The collection of climatic data in Afghanistan ceased around 1980, and few climatic data are available for Kabul until about 2003. The mean annual precipitation from 1956 to 1983 was estimated to be 312 mm (World Meteorological Organization 2004). Evaporation rates are high relative to annual total precipitation—approximately 1,600 mm/yr—and thus net groundwater recharge by precipitation in the Kabul Basin is essentially zero on an annual basis. During the late 1990s and early 2000s, little or no precipitation occurred in several years, and in 2001, only 175 mm of precipitation was reported for Kabul (International Water Management Institute 2002). For water years[5] 2004–2011, precipitation measured at the Kabul Airport was above average in 2005 and 2007, below average in 2004 and 2008, and average in other years (fig. 11.3; World Meteorological Organization 2004).
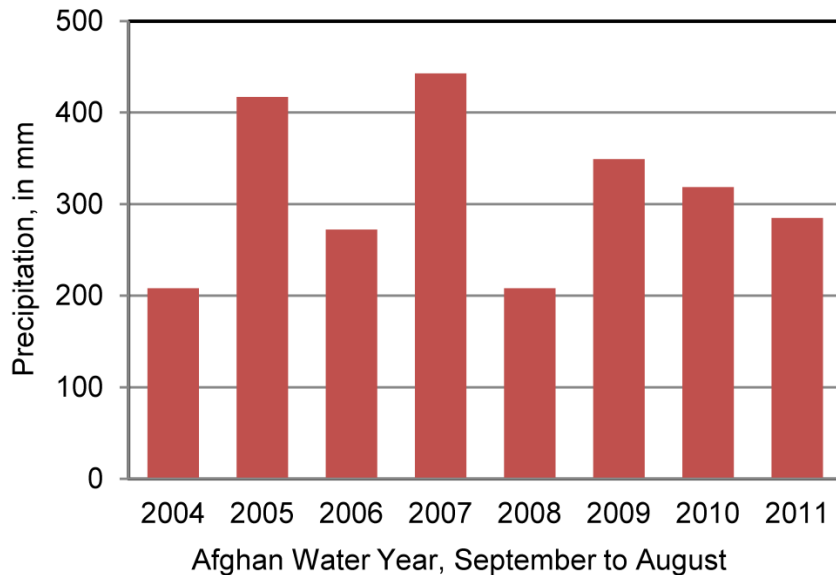

Figure 11.3. Annual precipitation at the Kabul Airport, Afghanistan, between September 1, 2003, and August 31, 2011.

11.1.2 Water Resources

11.1.2.1 Surface Water

A network of 12 streamgages (fig. 11.4) were operated within and adjacent to the Kabul Basin for various periods from 1959 until 1980 when the streamgages were discontinued. Historical streamflow records were compiled and entered into USGS databases (Olson and Williams-Sether 2010; Vining 2010) to enable calculation of historical base flow and recharge characteristics per unit area. Larger snow accumulation in northern drainages results in an average annual runoff of 0.020 m^3/s/km^2 for the northern stations compared with 0.004 m^3/s/km^2 for the southern stations (Mack et al. 2010).

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[5]Afghan water years are from September 1 of the previous year through August 31 of the water year referenced.
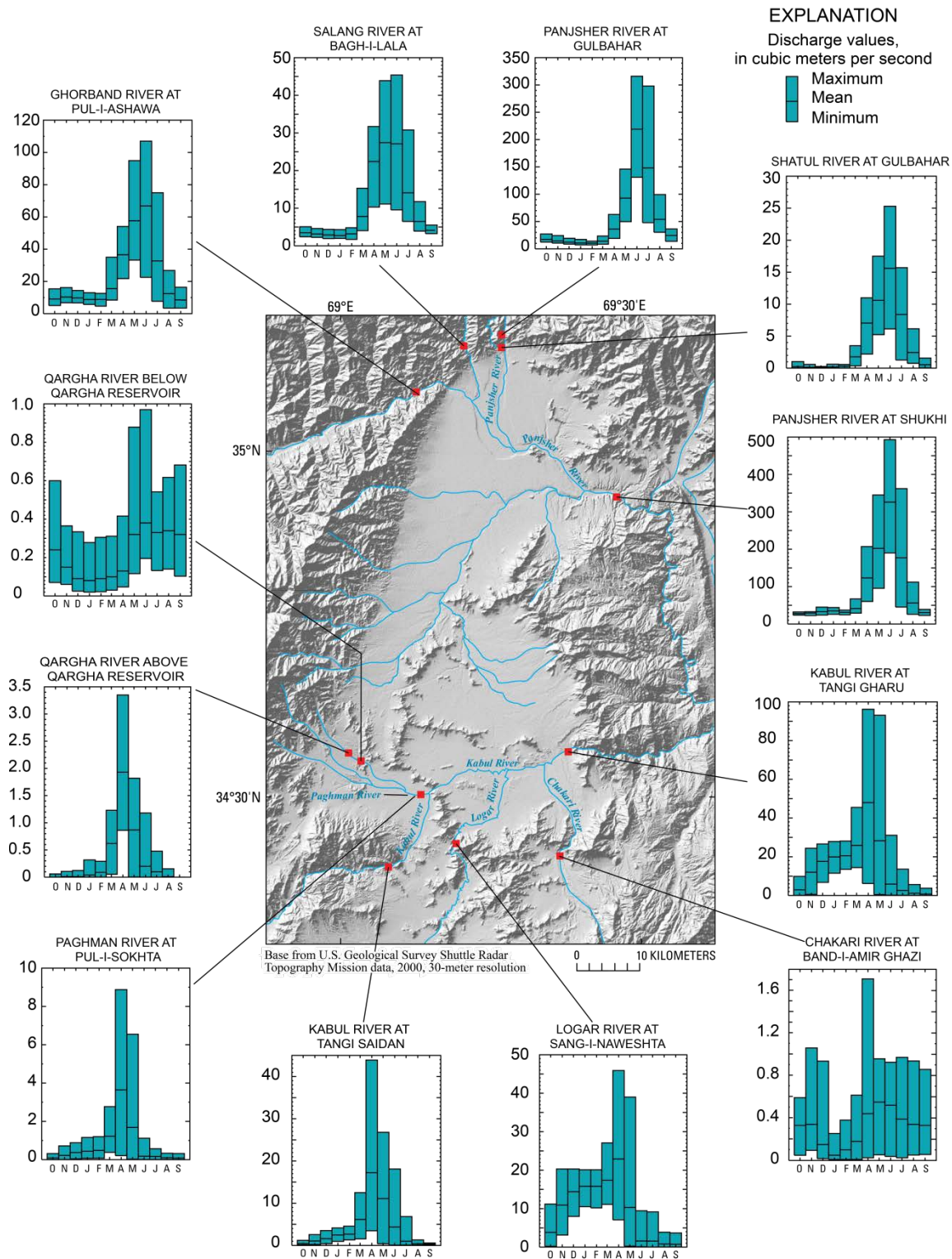
Figure 11.4. Maximum, minimum, and mean monthly discharges at 12 streamgages in the Kabul Basin between 1959 and 1980.

11.1.2.2 Groundwater

The AGS has operated a monthly water-level-monitoring network of more than 69 wells to better understand groundwater levels (fig. 11.5) in the basin since 2004 (Akbari et al. 2007).

Due to declining groundwater levels, some wells have been removed from the network, and 66 wells were used in this study. The Danish Committee for Aid to Afghan Refugees (DACAAR) has 10 wells in the Kabul Basin that were monitored for about the same period (Danish Committee for Aid to Afghan Refugees 2011). The AGS studied water-levels in wells in the Kabul Basin that ranged in depth from 4.9 to 30 m and generally were equipped with hand-operated or electric pumps. The DACAAR network wells are likely similar to the AGS wells.

Groundwater levels in parts of the Kabul Basin have declined substantially as a result of periods of below-average precipitation and increased water use during the 2000s. By 2007, groundwater levels in rural areas in the Kabul Basin were rising in response to an increase in precipitation to more average rates relative to antecedent drought conditions (fig. 11.3), while groundwater levels were declining in the city of Kabul as a result of increased water use (Mack et al. 2010). Groundwater levels in some areas of the Kabul Basin have been rising since 2004, such as at well 20 near Shomali in the northern part of the basin (fig. 11.6a). By contrast, groundwater levels in the city of Kabul have been declining. For example, AGS monitoring well 167 in the Central Kabul Subbasin indicated a 3-m decline in groundwater level from 2004 to 2007; however, from 2007 to 2012, the decline was about 15 m (fig. 11.6b).

Groundwater levels in the Kabul Basin were assessed using the seasonal Kendall test (Hirsch and Slack 1984; Helsel et al. 2006) to determine whether trends were evident. The slope of trends in groundwater levels is depicted in figure 11.7 and indicate where groundwater levels show no trend (slopes near zero) or levels are significantly rising (negative slope) or declining (positive slope). Between 2004 and 2012, groundwater levels rose in 16 wells; the median groundwater level rise was 0.31 m/yr, and rises generally were greater near streams in the northern Kabul Basin. Between 2004 and 2012, the median groundwater level decline observed in 19 wells was 0.76 m/yr, more than twice the median rate of groundwater level rise.

Groundwater level declines occur primarily in the urban areas of the Kabul Basin (fig. 11.7). Declines also tend to increase with greater distance from recharge sources, such as rivers or mountain fronts (the basin area adjacent to a mountain). The measured groundwater level trends are consistent with groundwater flow model simulated drawdowns resulting from increased withdrawals in and around the city of Kabul (Mack et al. 2010). Model simulations indicate that groundwater level declines may affect military facilities and government agencies in the city, all of which depend on groundwater for supply. By contrast, the northern Kabul Basin, which contains the Bagram Airfield, is less populated, receives more recharge (Mack et al. 2010), and groundwater levels have generally been rising between 2004 and 2012 (fig. 11.7).
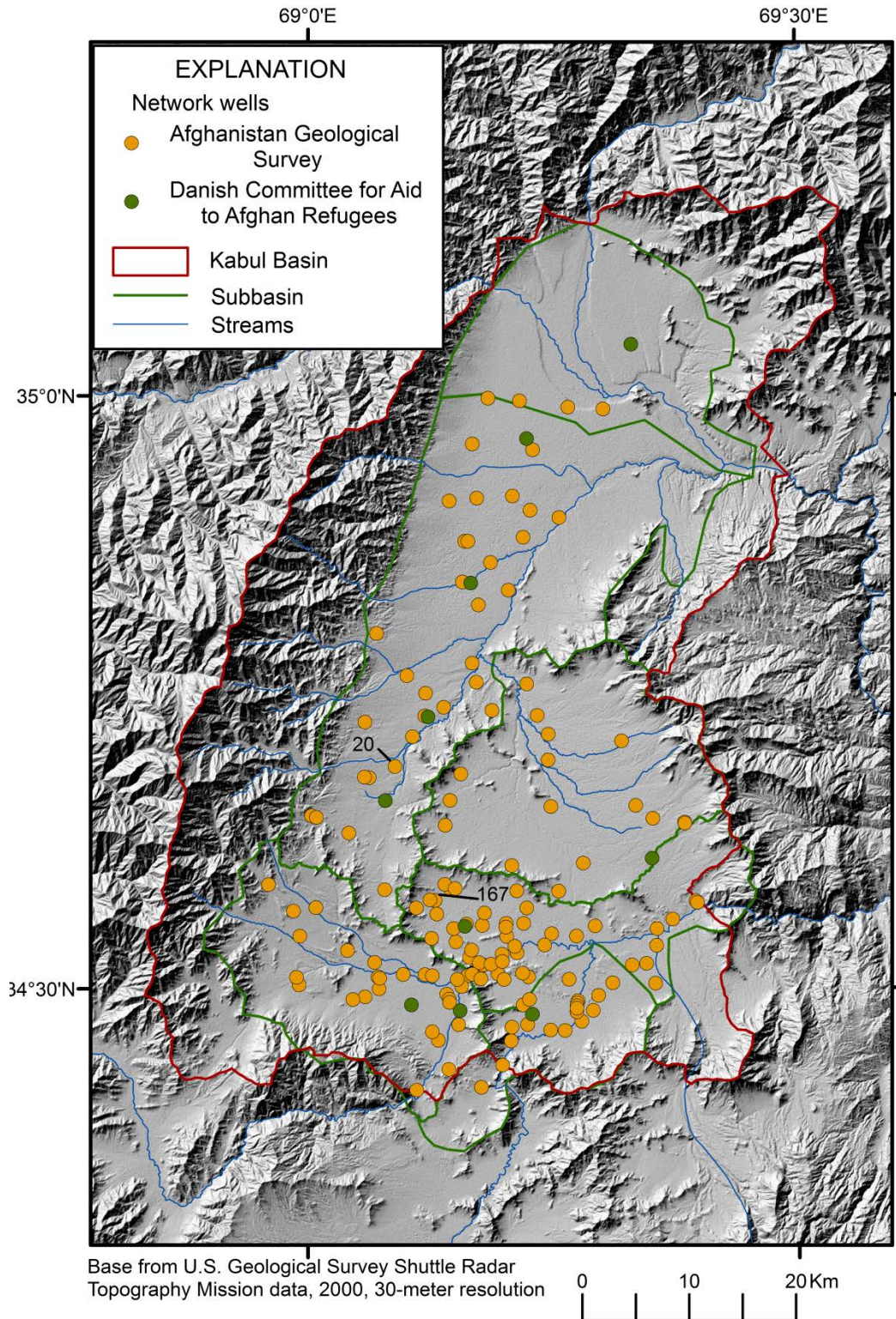
Figure 11.5. Location of wells in the groundwater level monitoring network in the Kabul Basin, Afghanistan.
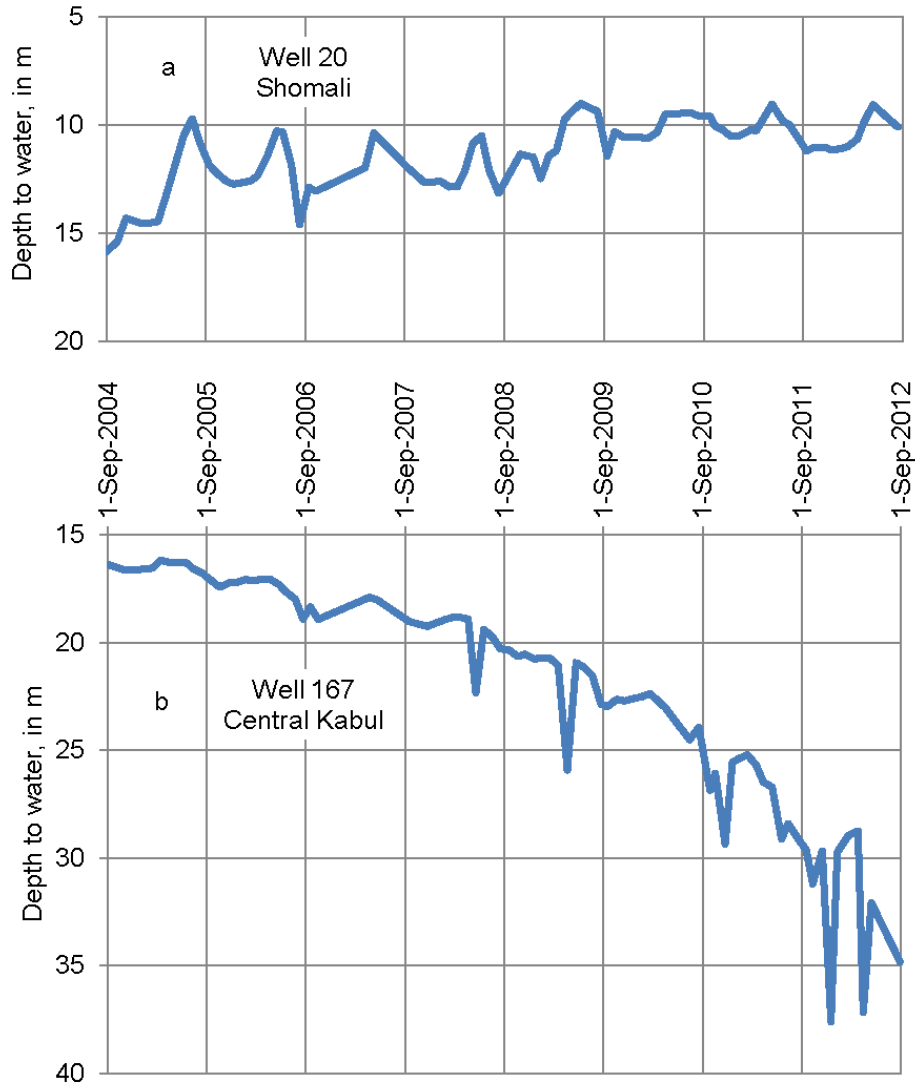
Figure 11.6. Monthly groundwater levels (measured as depth to water) from September 2004 to September 2012 at (a) well 20 in Shomali in the northern part of the basin and (b) well 167 in the Central Kabul Subbasin in the southern part of the basin in the Kabul Basin
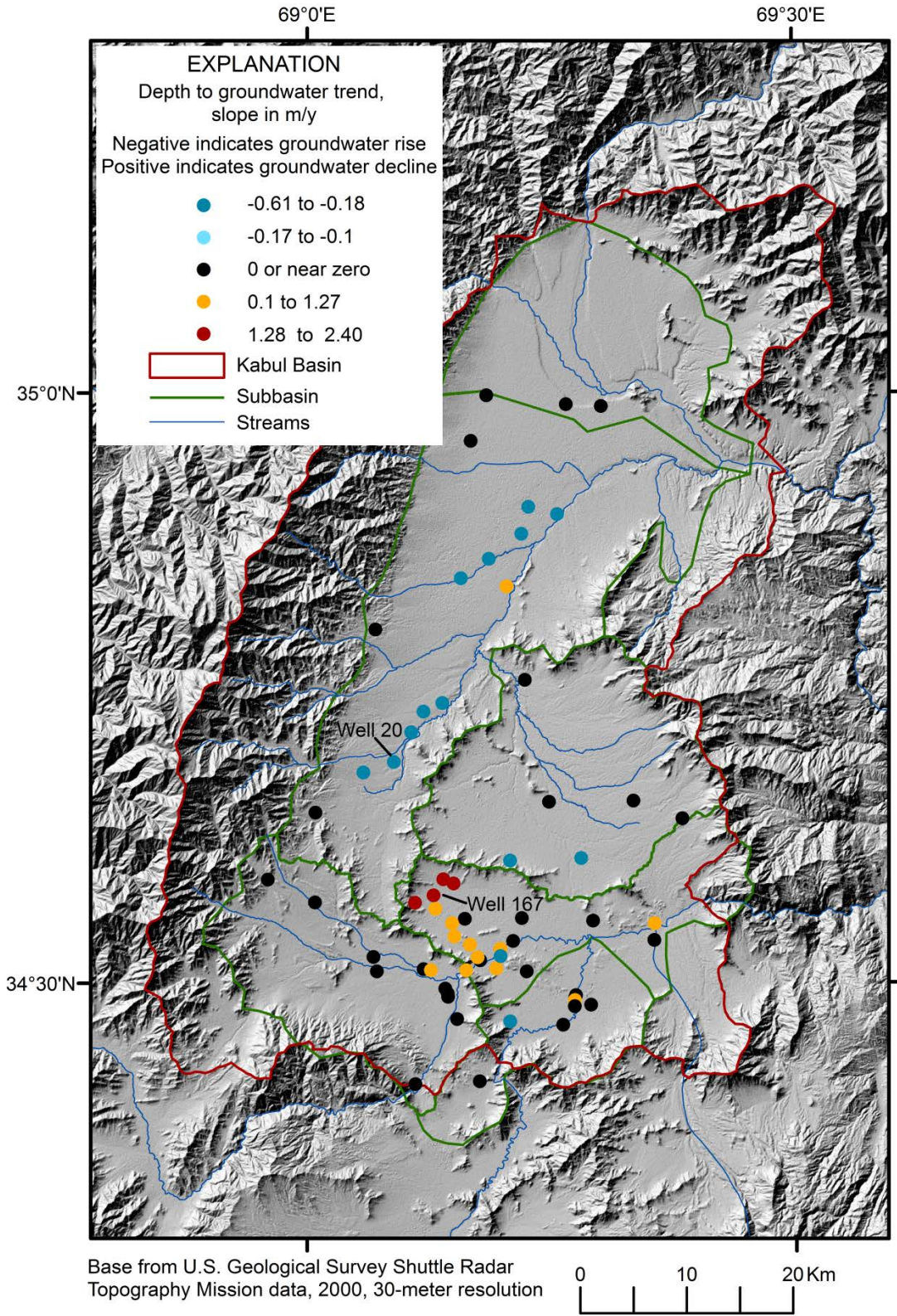
Figure 11.7. Groundwater level trends from 2004 to 2012 in the Kabul Basin, Afghanistan.

11.1.2.3 Water Quality

Concentrations of several chemical compounds were elevated in the city of Kabul and surrounding areas relative to less developed areas, suggesting anthropogenic contamination. Water-quality constituents and properties that indicated effect of urbanization included specific conductance, hardness measured as alkalinity, and concentrations of nitrate plus nitrite, bromide, magnesium, sodium, potassium, chloride, arsenic, boron, nickel, and zinc. Median values of specific conductance in groundwater ranged from 51µS/cm near the Kohe Safi Mountains (fig. 11.8) to 1,177 µS/cm in the city. The most notable concern for water quality was the presence of bacteria; total coliform and *E. coli* were detected in nearly all the groundwater samples in the basin. These indicators may be the result of poor sanitation and poor well construction.

11.1.3 Sustainability Considerations

Sustainability considerations in the Kabul Basin include the supply of water to shallow wells and the effects of potential climate change on water supply.

11.1.3.1 Shallow Wells

There are many shallow wells in the Kabul Basin that provide potable water to communities near military installations. Between 1997 and 2005, DACAAR and other nongovernmental organizations (NGOs) installed approximately 1,500 shallow wells in the Kabul Basin, with a median depth of 22 m. About 1,000 of these wells are in the three subbasins that include the city of Kabul (Safi and Vijselaar 2007). About 25 percent of the NGO wells that have a reported status in the city of Kabul were dry or inoperative compared with about 20 percent basinwide. Groundwater declines of 4 to 10 m occurred in the city of Kabul during the drought period of 1998 to 2002 (Banks and Soldal 2002; Safi 2005). With an improving standard of living, per person water-use rates and other water uses in the Kabul Basin likely will increase from current rates as will the likely number of dry shallow wells.
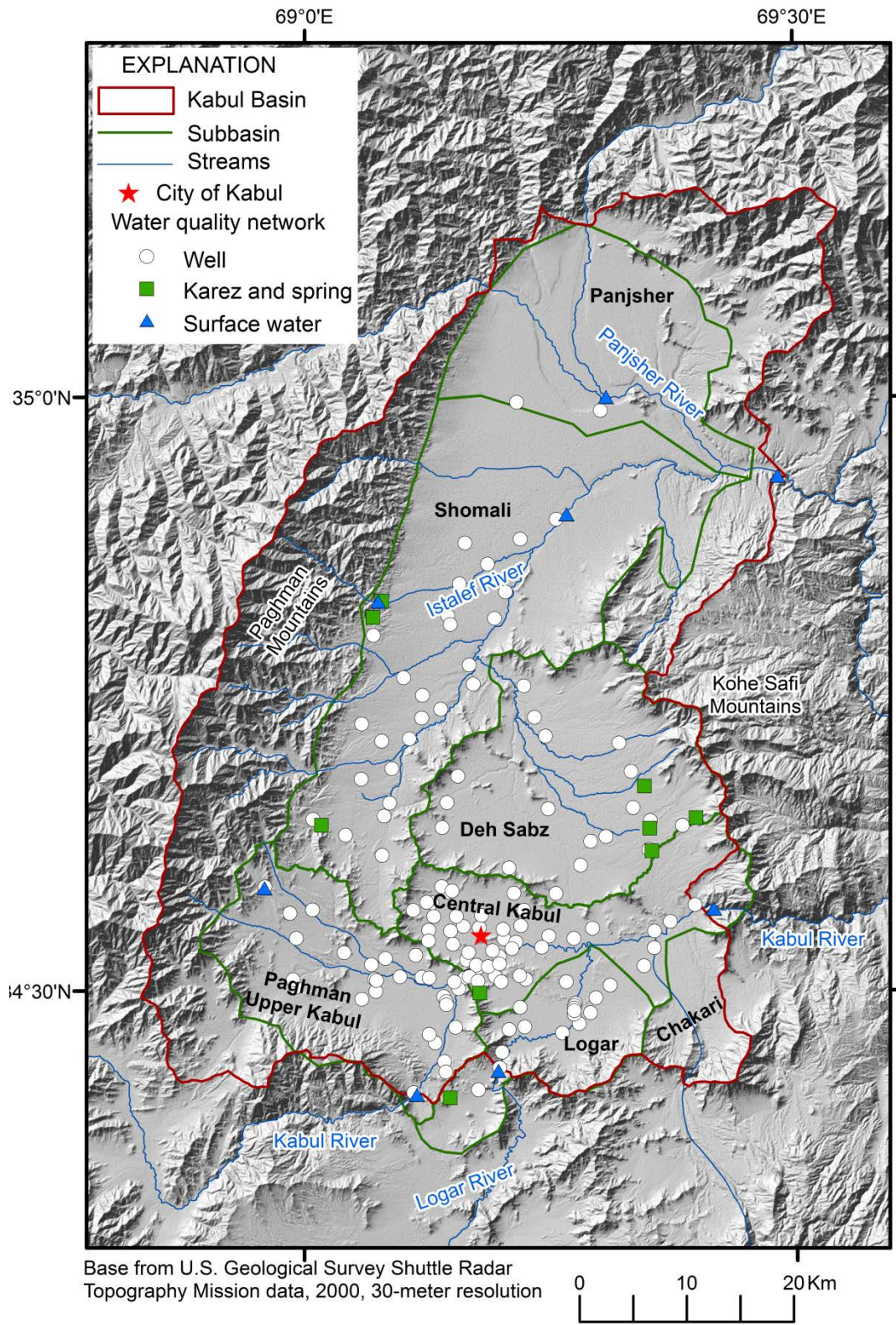
Figure 11.8. Water-quality sampling network in the Kabul Basin, Afghanistan.

11.1.3.2 Climate Trends and Predictions

Although few data are available for comparisons, previous (1961–1991) and recent (2003–2007) mean monthly temperatures indicate a general warming trend throughout the year (Mack et al. 2010). The largest change has been an increase of 5°C in the month of February. Vegetation trends from remotely sensed data indicate that the large increase in February temperatures is likely to have been consistent from 1992 through 2002 when temperature data are missing. The rate of change has been about 1°C for every 5 years since the early 1960s; although variable, the temperature continues to be higher than past measurements. Trends of this kind are expected to continue throughout the 21st century, particularly in mountainous regions (Christensen et al. 2007), including Central Asia. 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. An increase in surface temperatures in mountainous regions around the world is predicted fairly consistently by global 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. Modeling by Milly et al. (2005) projected a 20 to 30 percent decrease in runoff for Afghanistan by 2050 as a result of climate change. The implications for water resources at military installations and elsewhere in the Kabul Basin may be reduction in the amount of water available for supply.

11.2 Methods for Framing a Conceptual Model of Sustainability

### 11.2.1 Chemical and Isotopic Analyses of Water Quality

Surface-water and groundwater samples were collected from May 2006 through July 2007 and analyzed for (1) stable hydrogen and oxygen isotopic composition, (2) major- and minor-element chemical composition (30 elements), and (3) dissolved-gas composition (nitrogen, argon, carbon dioxide, oxygen, methane, helium). The apparent age of the sampled groundwater was estimated using chlorofluorocarbons (CFCs) trichlorofluoromethane (CFC–11), dichlorodifluoromethane (CFC–12), and triclorotrifluoroethane (CFC–113), tritium (3H) content, and carbon 14 (14C, two samples). Chemical constituent or isotopic composition samples included 80 groundwater and 76 surface-water samples. Mass fractions (picogram of constituent per kilogram of sample) of CFC–11, CFC–12, and CFC–113 were measured at 35 wells between May 2006 and June 2007, 6 springs in May and June 2006, and 14 surface-water sampling sites in February and June 2007. Samples were collected in a variety of settings, locations, and depths to help identify the source characteristics of groundwater recharge. Detailed descriptions of the chemical and isotopic methods of USGS–AGS water-quality investigations in the Kabul Basin are presented in Broshears et al. (2005) and Mack et al. (2010).

11.2.2 Conceptual Model and Groundwater Flow Simulation

A conceptual model of the Kabul Basin was designed to assess the regional groundwater flow system, including shallow unconsolidated sediment, deep semiconsolidated sediment, and bedrock aquifers, using MODFLOW-2000 (Harbaugh et al. 2000; Hill et al. 2000), a steady-state finite-difference groundwater flow model; the modeling analysis incorporates information provided by isotopic analyses. The lithology was grouped by major hydrologic characteristics

(primarily hydraulic conductivity) from surficial geology (Lindsay et al. 2005; Bohannon and Turner 2007) to form general geohydrologic zones (fig. 11.9).

West
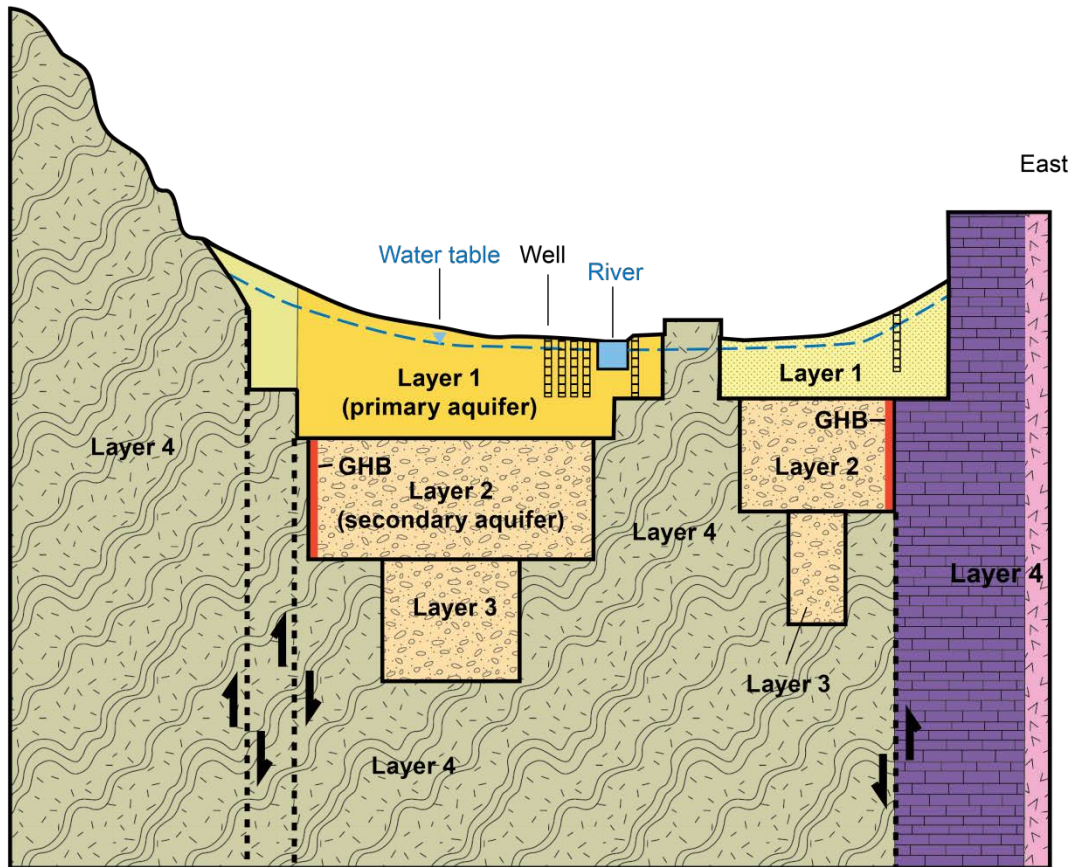
Not to scale

Geology modified from Bohannon and Turner 2007; and Lindsay et al. 2005

EXPLANATION

Sediments
- Fan alluvium
- Conglomerate
- Loess, alluvium
- Alluvium

Bedrock
- Sandstones (not shown)
- Limestones
- Metamorphics
- Intrusives

GHB General head boundary

Well

Fault and relative movement

The west and east side of the section approximately coincide with the watershed boundary for the Kabul Basin shown on figure 1.2.

Figure 11.9. Generalized hydrogeologic representation, including numerical-model layers, of the Kabul Basin, Afghanistan.

The model area was subdivided into a grid of 400-by-400-m cells, aligned with the primary axis of the Kabul Basin, and divided vertically into four layers (fig. 11.9). Layer 1 represents the primary surficial aquifer, consisting of unconsolidated sediment typically less than 80 m thick; layers 2 and 3, each 500 m thick, represent the secondary aquifer, consisting of

semiconsolidated conglomeritic sediment and bedrock; layer 4 is 1,000 m thick and represents the underlying bedrock at depth. Flows into and out of the model area included major streams, areal recharge from precipitation, inflows (head-dependent boundaries) at mountain fronts, leakage in irrigated areas, and domestic and commercial water use.

Water use in the model can be grouped into two major categories: (1) combined municipal and domestic use and (2) agricultural irrigation. Municipal and domestic use was estimated using 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 applied to a 2005 regional population distribution estimated by the Oak Ridge National Laboratory (2007) LandScan project. The estimated population by 1-km grid cells ranged from 0 to 10 in rural areas to about 62,000 in the city (fig. 11.10). Populated areas indicate where water is or has been available from karezes (a historical water supply system that accessed the water table), streamflow diversions, or shallow groundwater wells.

Currently (2012), there are few waste water systems in the Kabul Basin; waste water is discharged in leach fields on site or, in many cases, residents use nearby drainage ditches. Agricultural water use was estimated by an energy-balance method and remotely sensed temperatures (Senay et al. 2007). Agricultural water use occurs primarily in northern subbasins and to lesser degree in the southeastern subbasins and is almost entirely supplied by karezes and streamflow diversions (fig. 11.11).

Steady-state groundwater flow in the aquifer system was simulated using mean annual inflows and outflows (table 11.1). The groundwater flow model was calibrated to recent (2007) water levels and historical (pre-1980s) stream flows. Because of limited streamflow data suitable for calibration, the model is considered to provide a conceptual understanding of the groundwater flow system and probable flow conditions rather than a fully calibrated understanding. The general structure of the groundwater flow model is shown in figure 11.9. Total base flows, river inflows, estimated upland drainage, and estimated direct recharge were compared with outflows at the Panjsher and Kabul Rivers from the northern and southern basins, respectively (fig. 11.4, table 11.1). The total inflow to the northern subbasins is about five times the total inflow to the southern subbasins. Detailed discussion of the numerical representation, simulation of inflows and outflows, and model limitations are provided in Mack et al. (2010).

In the lower altitude areas near the centers of the subbasins, the simulated groundwater levels (fig. 11.12) were generally within 10 m of the observed levels and generally matched regional measured levels. 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 large contrasts in hydrogeologic environments. Although levels simulated by the model may not be accurate at a local scale, the model can be used to simulate the regional groundwater flow system and the effect of natural and anthropogenic stresses on the system.
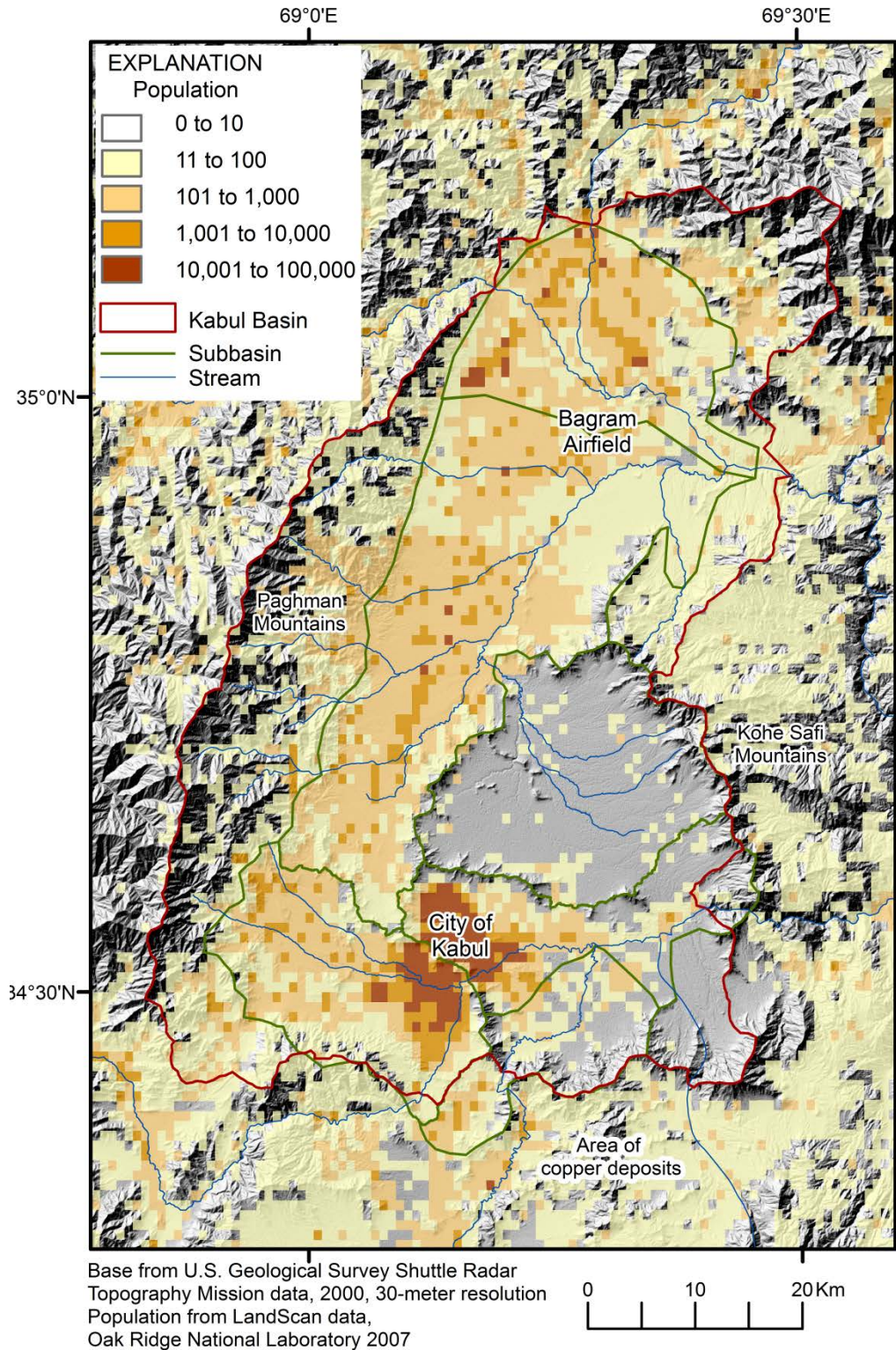
Figure 11.10. Estimated population distribution in the Kabul Basin, Afghanistan, in 2005. Data are from Oak Ridge National Laboratory (2007).
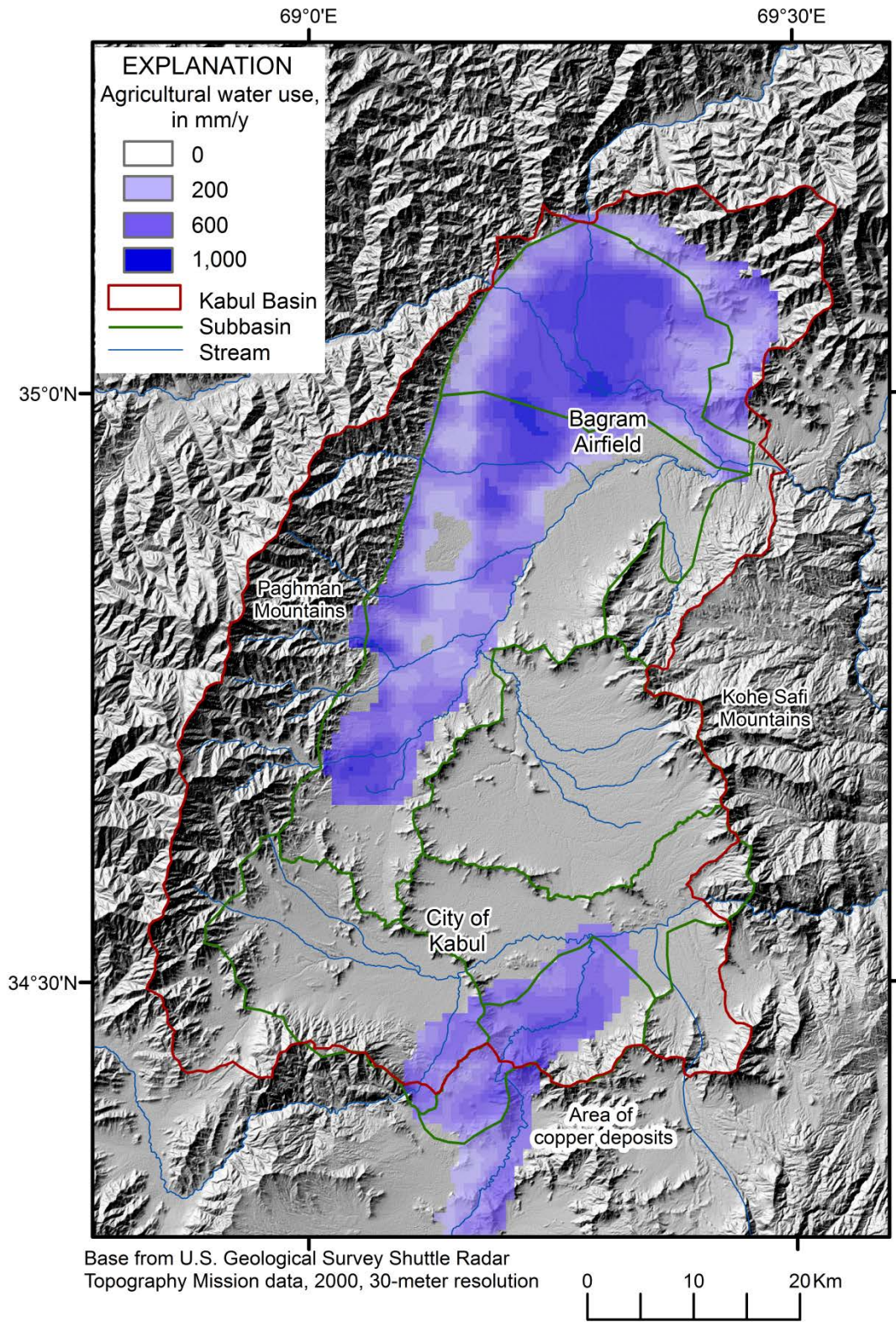
Figure 11.11. Areas of agricultural water use in the Kabul Basin, Afghanistan.

Table 11.1 Annual mean balance of water in the (a) northern and (b) southern subbasins of the Kabul Basin, Afghanistan.

[Flows and rates are accurate to no more than two significant figures; data are shown unrounded for computational purposes only]

Flow	Drainage area, in km^2	Recharge rate, in m^3/d
a. Northern subbasin areas (Panjsher River and Shomali subbasins)		
Inflow:		
Base flow:		
Gorband River	4,032	1,775,435
Salang River	435	837,178
Panjsher River at Gulbahar	3,538	3,723,924
Shatul River	202	290,461
Recharge at a rate of 0.00067 m/d	—	—
Upland drainage from Paghman Mtns.	321	468,686
Direct recharge on subbasin surfaces	1,698	1,940,571
Total inflow	—	9,036,256
Outflow, base flow at Panjsher River at Shuki	10,857	6,150,398
Difference between inflows plus recharge and outflow[1]	—	2,081,599
Inflow as a percent of outflow[1]	—	134
Loss, estimated evapotranspiration	700	915,422
b. Southern subbasin areas (Paghman, Central and Upper Kabul, Logar, and Chakari subbasins)		
Inflow:		
Base flow:		
Paghman River	424	49,524
Kabul River at Tangi Saidan	1,663	303,903
Logar River	11,461	690,416
Chakari River	302	25,744
Recharge at a rate of 0.00067 m/d	—	—
Direct recharge on subbasin surfaces	780	891,429
Total	—	1,589,587
Outflow, base flow at Kabul River at Tangi Gharu	14,556	1,078,018
Difference between inflows plus recharge and outflow[1]	—	511,569
Inflow as a percentage of outflow[1]	—	147
Loss, estimated evapotranspiration	110	51,547

[1]Because of changes in storage, unknown components in the water balance, and inflows and outflows being annual mean values, inflows do not necessarily equal outflows.

Simulated groundwater levels (fig. 11.12) illustrate the effects of recharge to the surficial aquifer due to leakage from the perennial streams that drain into the valley from the Paghman Mountains. Additionally, the amount of streamflow entering the northern Kabul Basin, which contributes leakage on irrigated areas, is much greater than the streamflow entering the southern Kabul Basin (table 11.1 baseflow in; fig. 11.4). Chemical analyses indicate that mountain-front recharge adjacent to the Paghman and Kohe Safi Mountains is an important source of recharge to the Kabul Basin (fig. 11.12). The stratigraphy of the Paghman Mountains comprises metamorphic rocks, which generally have relatively low groundwater storage and transmissivity. Because there are a number of faults along the western mountain front of Kabul Basin, along the Paghman Mountains (fig. 11.2), the bedrock is likely to be more highly fractured and to have higher groundwater storage and transmissivity than rocks elsewhere in the Kabul Basin.
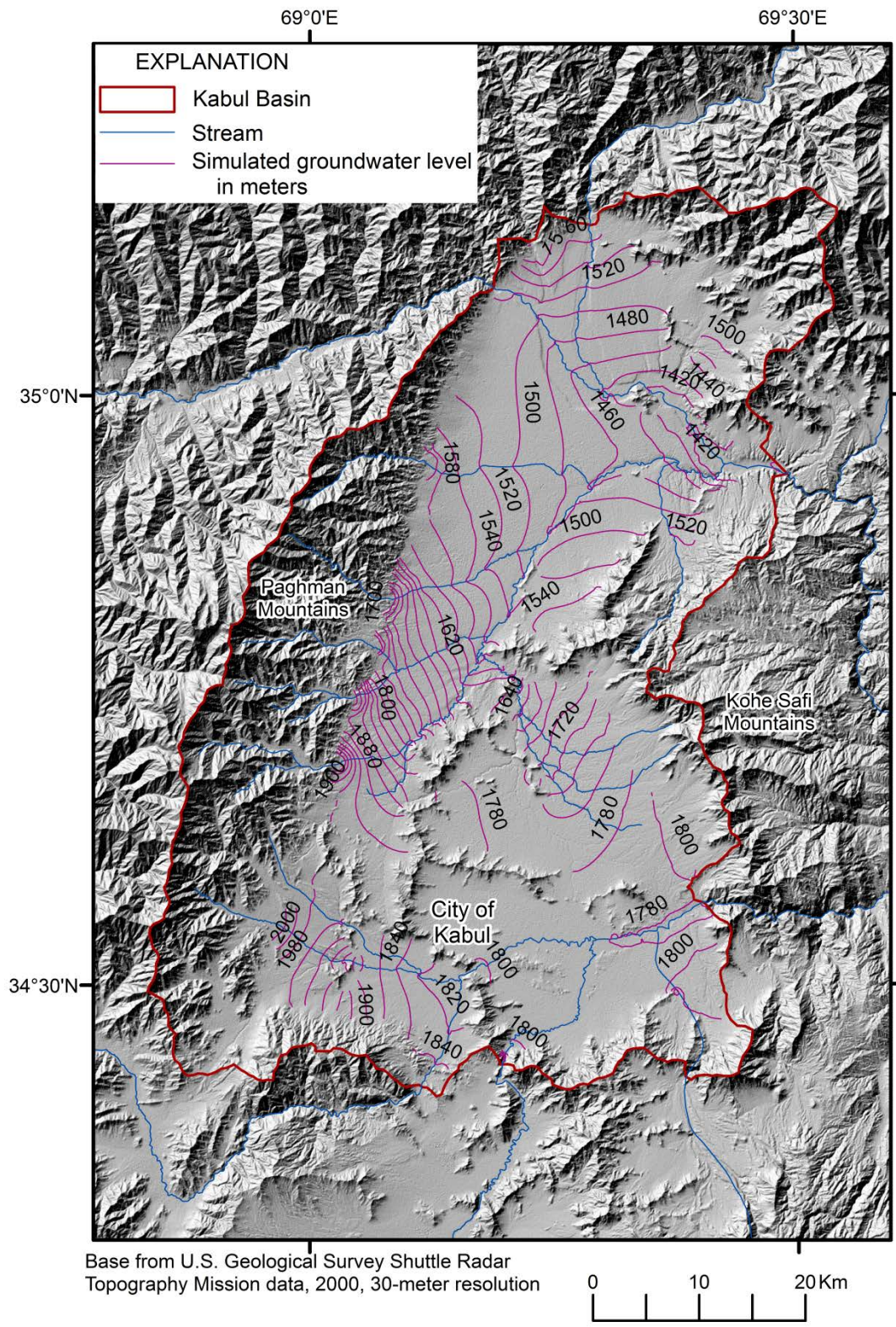
Figure 11.12. Simulated groundwater levels in primary surficial aquifer (model layer 1) in the Kabul Basin, Afghanistan.

Application of Sustainability Analysis to the Kabul Basin

The effect of an estimated population of 9 million [Mack et al. 2010] in the Kabul Basin in 2057 on water resources was simulated by increased domestic and municipal withdrawals in the surficial aquifers. Estimating the sustainability of water in the Kabul Basin requires estimating the balance of flow in the system through a combined use of numerical modeling and detailed isotopic analysis of groundwaters and surface waters. A general water balance consisting of mean base flows in and out of the rivers in the Kabul Basin was calculated for the northern and southern subbasin areas (table 11.1). Chemical and isotopic analyses of surface water and groundwater help in characterizing the distribution of recharge to the upper aquifer and the source and age of water in the lower aquifer to improve the analysis of groundwater sustainability.

Chemical and Isotopic Analyses of Water

The samples most depleted in stable hydrogen and oxygen isotopic composition (2H and 18O) were those from the Panjsher River; this isotopic result reflects snow melt from high-altitude source areas. Samples from the Istalef and Paghman Rivers (fig. 11.8) were most enriched in 2H and 18O; this result is consistent with the relatively low-altitude source areas for these rivers in the foothills of the Paghman Mountains west of the Kabul Basin (fig. 11.1). None of the surface-water bodies studied were affected by significant evaporation.

Some groundwater had chloride concentrations as high as 1,650 mg/L, which is 10 to 50 times greater than that in surface waters. Had these chloride enrichments been caused by evaporative concentration, there likely would have been substantial enrichments in 2H and 18O. This finding that the surface water and groundwater chemical compositions were similar suggests that there was little evaporation prior to recharge. Mass concentration ratios of some of the dissolved solutes to dissolved chloride in groundwater were similar to the ratios in nearby surface-water samples. The similarities of the mass ratios of more conservative solutes (sodium, sulfate, manganese) with chloride in groundwater to the same ratios for surface water together with the isotopic data suggest a surface-water source (river and irrigation leakage) for many of the groundwater samples.

All the water samples analyzed from the upper aquifer, springs (essentially groundwater discharge), and surface water contained CFCs and tritium and can be considered young water (post-1945). An 3H concentration greater than 0.5 tritium unit indicates waters that are post-1955 in age or waters that are mixtures of 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 young water, and the presence of CFC–113 indicates post-1957 water or mixtures of pre-1957 water with post-1957 water. The median mass fractions of CFC–11, CFC–12, and CFC–113 in 41 groundwater samples (35 wells and 6 springs) were 309, 221, and 39 pg/kg, respectively. 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 (table 11.2). Because most of the samples are pumped from open boreholes, the CFC mass fractions are likely measured in mixed water, and thus the age is referred to as the median or apparent age. Two ^{14}C samples collected from the top of the lower aquifer, which is used less commonly for water supply, indicate groundwater residence times of hundreds to thousands of years. The results indicate that groundwater in the lower aquifer is orders of magnitude older than that of the upper aquifer.

Table 11.2 Summary of average ages, percentages of young water, and percentages of modern water based on concentrations of CFCs, tritium, and carbon 14 in groundwater in the Kabul Basin, Afghanistan.

[^{14}C, carbon 14; CFC–11, trichlorofluoromethane; CFC–12, dichlorodifluoromethane; CFC–113, triclorotrifluoroethane; TU, tritium unit]

| Groundwater subbasin or area | Average piston flow ages, in years[1] | | | Average ratio-based ages and percentage of modern water[1] | | | | Average percentage of modern water | | | Tritium, in TU | ^{14}C[2] | |
| | | | | CFC–113:CFC–12 | | CFC–113:CFC–11 | | | | | | | |
	CFC–11	CFC–12	CFC–113	Age	Percentage of modern water from CFC–113	Age	Percentage of modern water from CFC–113	CFC–11	CFC–12	CFC–113		Age	Percentage of modern water from ^{14}C
Kohe Safi Mountain front	30	21	20	20	95	11	84	55	81	67	6.1		
Paghman Mountain front	28	23	21	23	77	17	71	85	86	68	12		
Shomali	23	21	19	15	87	14	81	86	88	81	13.5	300	84
												2,800	58
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.
[2]From two samples collected at depths of 73 and 100 meters.

Groundwater samples from the upper aquifer generally are relatively young because they contain CFCs and tritium or are mixtures that contain some young water (table 11.2). Most samples appear to be water infiltrated from streams and rivers within the past 30 years but the samples likely have been affected by mixing processes. Groundwater age generally increases with depth below the water table (fig. 11.13). The observed depth-to-age gradients suggest infiltration rates, adjusted for an assumed porosity of 25 percent, of 0.35 to 0.7 m/yr. These rates are considerably greater 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. However, the results for one sample near the Kohe Safi Mountains did not follow the general depth and age trend (fig. 11.13). This sample was from a deep well at the eastern area of the Deh Sabz subbasin (fig. 11.1) where there is likely to be relatively little direct recharge and no recharge from irrigation leakage. The anomalously young age of this sample suggests a relatively rapid source of groundwater inflow (mountain front recharge) from the adjacent Kohe Safi Mountains.
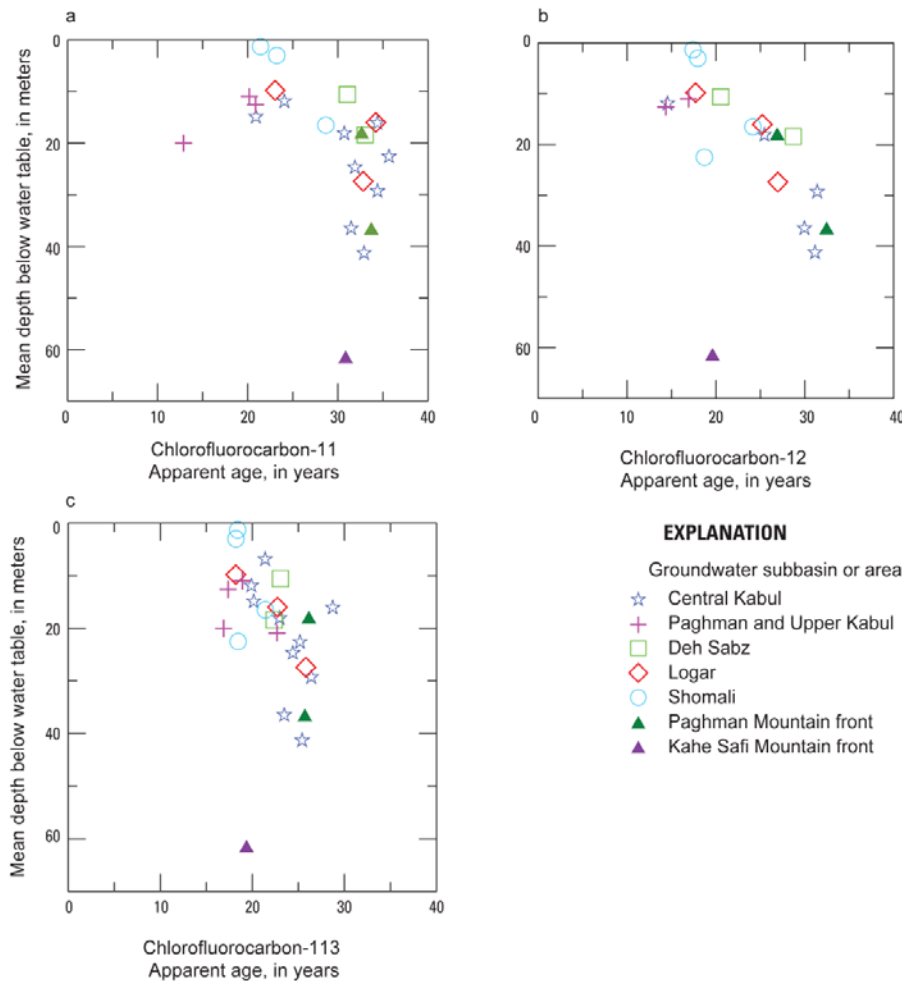

Figure 11.13. Apparent (piston-flow) ages as a function of depth below the water table based on (a) CFC–11, (b) CFC–12, and (c) CFC–113.
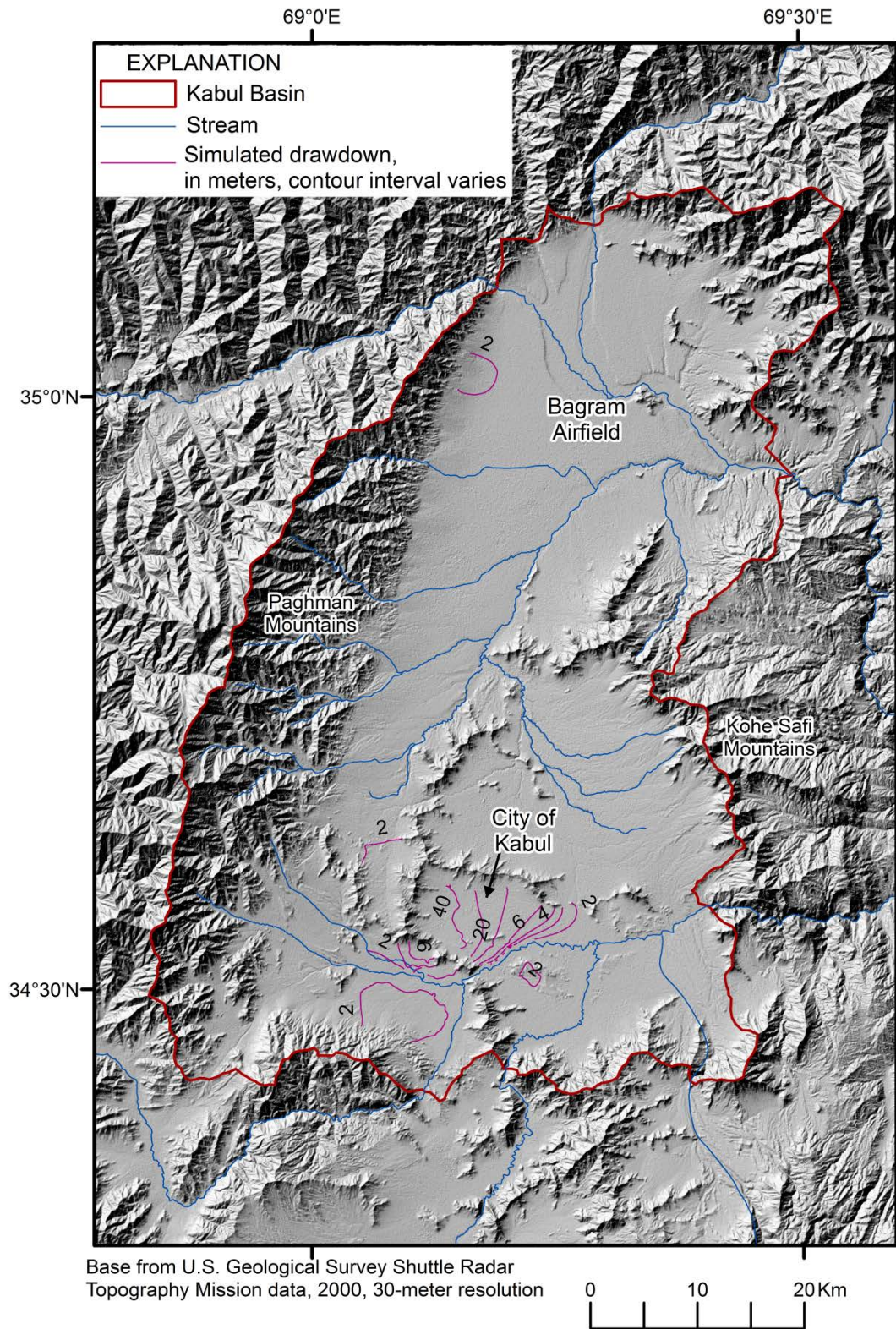
Figure 11.14. Simulated regional drawdown in the upper aquifer caused by a sixfold increase in water use in the Kabul Basin, Afghanistan.

Sustainability of Groundwater Resources in the Kabul Basin

Based on analysis of projections from United Nations Population Division (2008) and United Nations Economic and Social Commission for Asia and the Pacific (2008), population growth and increasing per capita water use were estimated to result in about a sixfold increase in total annual municipal and domestic water use by 2057 (Mack et al. 2010). For purposes of this analysis, the population distribution (fig. 11.10) and the extent of and use of irrigation water were assumed to be the same as recent (2007) conditions.

A sixfold increase in water withdrawals from the upper aquifer and subsequent water distribution following current population patterns could cause many existing shallow wells to become dry. The simulated groundwater declines (drawdowns), ranging from 2 to 40 m, are largest in urbanized areas, particularly the center of the city of Kabul (fig. 11.15). The mean depth of NGO-installed community supply wells in the Kabul Basin is about 22 m, and the mean nonpumped depth to water in those wells is about 12 m. Therefore, on average, very little water (a column of about 10 m) is available for drawdown caused by pumping or seasonal fluctuations in water levels. Military installations in the city of Kabul and surrounding areas, which probably have deeper wells than community supplies, may also be affected by simulated groundwater level declines of 10 to 40 m (fig. 11.14). Military installations in the northern basins likely are less affected due to the greater water inflows in this area (table 11.1).

Future, more centralized water systems are likely to access water from the lower aquifer for additional water supplies and may not greatly affect water levels in shallow wells As an example, simulations of large groundwater withdrawals (10,000 m^3/d) from six hypothetical wells located in the top 100 m of the deeper conglomeritic aquifer indicate that individual large groundwater withdrawals likely do not substantially affect shallow wells (fig. 11.15; Mack et al. 2010). However, multiple large withdrawal wells in the deep aquifer, particularly in the smaller subbasins around the city, would likely interfere with each other and collectively could affect water levels in shallow wells. Large groundwater withdrawals may be more sustainable in the northern areas of the Kabul Basin where recharge along the mountain fronts and from surface water inflows are greater. Withdrawals from the deep aquifer also may be free of the bacterial contamination that affects the shallow aquifer. However, groundwater in the deep aquifer, with ages of thousands of years and long flow paths, may have other water-quality characteristics unsuitable for supply, such as high dissolved solids and potentially trace elements, such as arsenic, manganese, and uranium. For example, in the southwestern United States, arsenic was found to increase with longer groundwater flow paths in similar, low-recharge, basin-fill aquifers (Anning et al. 2012).
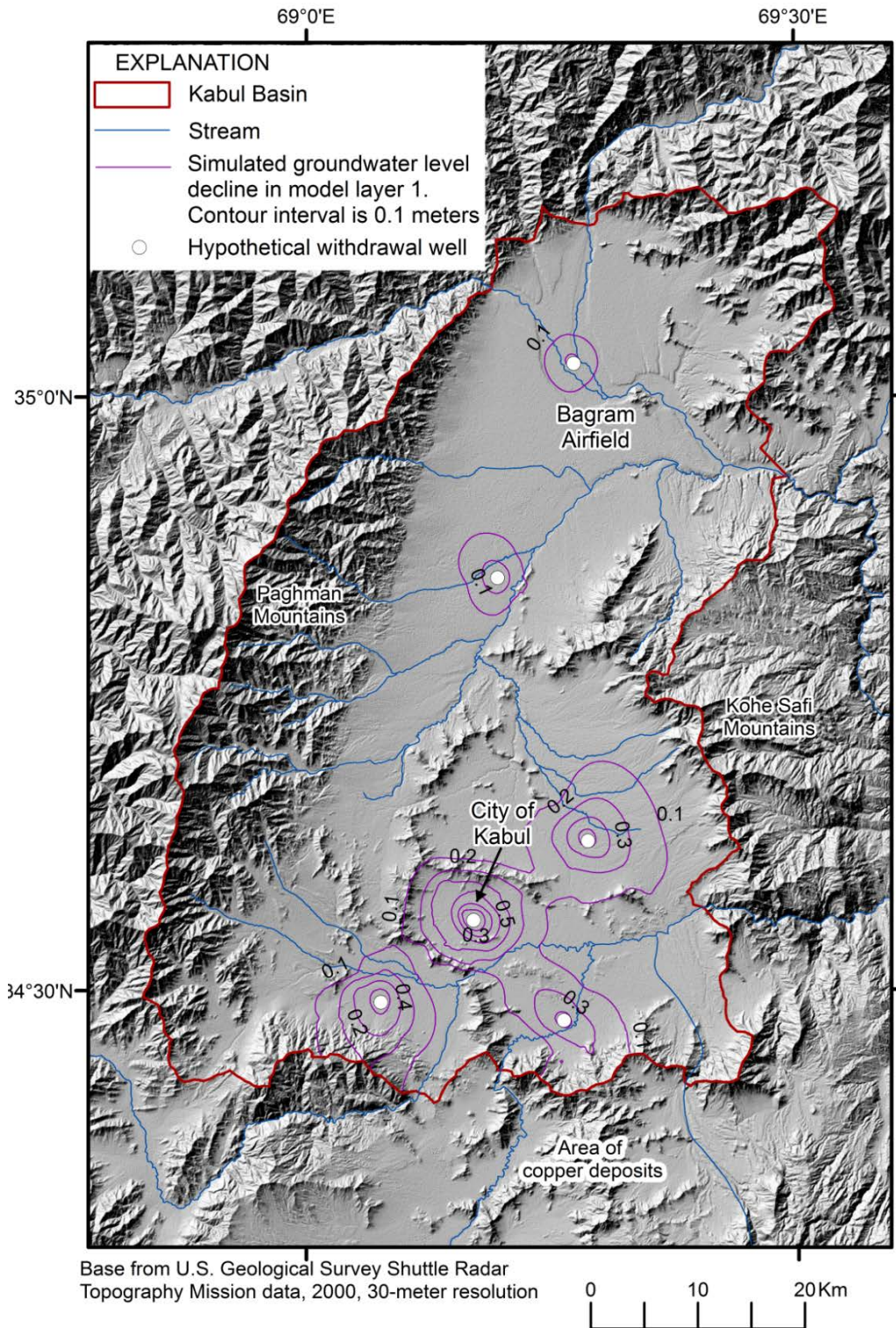
Figure 11.15. Simulated drawdown in the primary surficial aquifer (model layer 1) by large withdrawals from deep aquifers in the Kabul Basin, Afghanistan

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Summary

Complex groundwater resource sustainability questions can be addressed with a hydrogeologic investigation using isotopic and chemical analyses and groundwater flow modeling. Groundwater levels in the Kabul Basin have declined considerably since the 1960s as a result of below-average precipitation in the early 2000s and increasing population and associated water use during the past decade. Declines of a few meters to more than 10 m have been reported between the 1960s and early 2000s for some parts of the Kabul Basin. Further groundwater level declines of more than 10 m have been measured in the city of Kabul in the past decade in areas of concern to military installations of Afghanistan, the United States, and other nations.

Basic hydrogeologic methods, including geologic mapping and water-level and streamflow-data analyses, were used to determine the primary characteristics of the Kabul Basin. Detailed chemical and isotopic information was used to assess the distribution of recharge and determine the likely sources of water in the Kabul Basin. Analyses indicate that much of the groundwater in the Kabul Basin appears to have recharged from surface water, either by infiltration of river water or irrigation leakage. Additionally, groundwater inflow at the mountain fronts is a source of recharge in those areas. The city of Kabul is distant from these sources of recharge and it is estimated that groundwater beneath the city is likely thousands of years old.

Simulated groundwater flow in the Kabul Basin, with the anticipated population growth and consequent sixfold annual water use increase by 2057, indicates that the sustainability of future water supplies may be of concern at military installations in and around the city of Kabul. An analysis of groundwater level trends from 2004 to 2012 produced results consistent with analyses using the groundwater model. The sustainability of groundwater is favorable in the area of the Bagram Airfield in the northern part of the Kabul Basin. Military installations in the Kabul Basin may develop a more secure water supply by completing future water-supply wells in the deeper aquifer, which is less responsive to potential effects of changes in climate and shallow withdrawals. However, careful evaluation and management of new withdrawals, along with monitoring climate trends and effects of other withdrawals, will be needed to protect existing water supplies for the surrounding communities. With uncertainties in the effects of potential climate change and population growth, models that simulate groundwater flow provide a tool for assessing alternate management scenarios for improving the sustainable use of water resources at military installations in the Kabul Basin, Afghanistan.

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