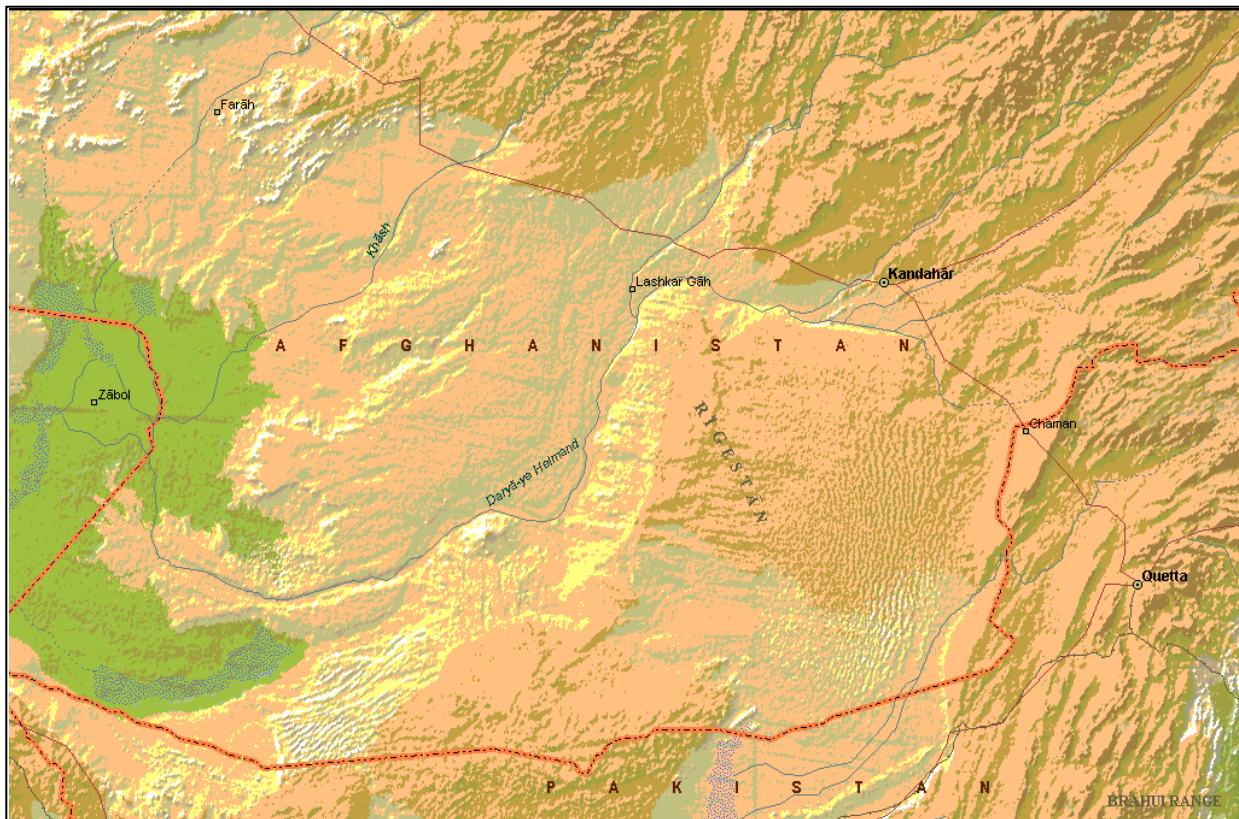


USAID/Kabul

Kandahar Groundwater Resource Assessment

June 30, 2003



Final Report

Contract No. LAG-I-00-98-00034-00 Task Order #806

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Appendix A Kandahar Groundwater Study Scope of Work

LIST OF ACRONYMS

Central Authority for Water Supply and Sewerage	CAWSS
Danish Committee for Aid to Afghan Refugees	DACAAR
International Committee of the Red Cross	ICRC
Khalid Sabawoon Engineering.....	KSE
Norwegian Church Aid-Afghanistan Program.....	NCAAP
Production Well.....	PW
Swiss Agency for Development and Cooperation	SDC
Test/Observation Well	TW
Total Dissolved Solids	TDS
United Nations.....	UN
United Nations High Commissioner for Refugees.....	UNHCR
United Nations Office for the Coordination of Humanitarian Affairs	UNOCHA
United States Bureau of Reclamation.....	USBR
United States Geological Survey	USGS

CONVERSION TABLE

Multiply	by	to obtain
Liter (L)	0.26	US Gallons
Liter (L)	0.001	Cubic Meters (m ³)
Meters (m)	3.28	Feet (ft)
Cubic meters (m ³)	35.3	Cubic feet (ft ³)
Liters per second (L/s)	15.8	US Gallons per minute (gpm)
Cubic meters/ hour (m ³ /h)	0.28	Liters per second (L/s)
Liters per second (L/s)	86.4	Cubic meters per day m ³ /D
Liters per second per meter (L/s/m) {Specific capacity}	4.9	US Gallons per minute per foot (gpm/ft)
Square meters per day (m ² /D) {Transmissivity}	80	US Gallons per day per foot (gpd/ft)
Meters/day (m/D) {Permeability}	24.5	US Gallons per day per square foot (gpd/ft ²)

Section 1

Executive Summary

1.1 Introduction

Between October 2002 and May 2003, CDM performed an initial assessment of groundwater resources in Kandahar, Afghanistan, for the U.S. Agency for International Development (USAID). The work was conducted through Task Order #06 under the Engineering Indefinite Quantity Contract (IQC) [Contract No. LAG-I-00-98-00034-00] to assess water supply and sanitation needs in this war-torn country. The assessment in Kandahar is referenced as Option B, Kan#1 GW Vulnerability Assessment (ref. 3.2.2.7).

Key personnel included Eddy Perez, home office task order manager, Washington D.C.; Ken Choquette, chief-of-party, Kabul; and, Jim Carr, lead hydrogeologist and report author. In Kandahar, Carr was assisted by John Crippen P.E., Yar Mohammad (Geologist), Eng. Abdul Rahman, Eng. Rahmat Gul and Khalil-Ullah Tareen (translator and coordinator). Scott Coffey (CDM) helped interpret data and prepared hydrogeologic graphics. The author wishes to acknowledge the assistance and constant courtesy many local officials offered him and other CDM staff during the project.

1.2 Background

Five years of drought – the last three with virtually no rain – have dramatically lowered water levels in Kandahar. Hundreds of shallow wells have dried up. Mature orchards and vineyards are dead or dying; garden farmers traditionally served by centuries-old karezes have left their fields to seek work in the city.

In Kandahar, the drought has created well-founded concerns regarding current and future reliability of the public water supply. The Central Authority for Water Supply and Sewerage (CAWSS) operates Kandahar's public water system serving a population of 500,000 by pumping about 5,000 m³/D of groundwater

from six to 10 wells through a piped system. After 20 years of war and conflict, CAWSS has maintained limited well records and operational data, so very little verifiable information is available regarding these wells, or how sustained drought has impacted their yield, altered water quality, or impacted aquifer vulnerability, and the ability of the wells to continue to satisfy the need of the city's burgeoning population. Static and pumping water levels cannot be sounded, and there is no practical means of measuring individual well discharge.

The most recent local weather records (1963-1971) put average precipitation at 141 mm (5.4 inches) per year and evaporation at more than 1,500 mm (58 inches) per year. In fact, the record shows no month of an average year where precipitation exceeds evaporation. This combination provides no opportunity for local rainfall to recharge local aquifers.

The Arghandab River, about six kilometers west of the city, is the only major stream in the area. A bedrock ridge between the river and city prevents hydraulic connection between river system water and the Kandahar Basin. However, west of town the ridge is offset, forming the 2 km wide Gap – occupied by the main east-west highway and perhaps a dozen small irrigation canals. For centuries, these canals and diversions carried water from the river to Kandahar. In 1971, the U.S. Geological Survey (USGS) reported the river had an average annual discharge of 40 m³/second (1,400 cfs). In 2002, this wide river was dry. River discharge is controlled by the Dullah Dam that also diverts water to a large canal (Lo Walla) that passes through a tunnel in the ridge to carry water some 15 km across the Kandahar Plain. During 2002 and most of 2001, the Lo Walla and all the other smaller canals were dry.

1.3 Project Objectives

Project objectives were to:

- Estimate the capacity of the resource;
- Identify water quality and aquifer vulnerability issues;
- Evaluate long-term capability of the existing resource; and,
- Prioritize other potential sources capable of reinforcing or replacing the existing supply.

CDM performed the following tasks:

1. Compiled all available local groundwater reports, maps and data;
2. Developed protocols for data collection, drilling, testing, and water quality analysis;
3. Collected new data – well logs, water level, water quality, and aquifer characteristics;
4. Compiled and evaluated all available data;
5. Trained local engineers and geologists to collect accurate hydrogeologic data and maintain useable records;
6. Analyzed all available data and made preliminary estimates of groundwater resource potential;
7. Identified data gaps and prioritized data collection needs;
8. Identified and prioritized opportunities for developing and improving groundwater supply;
9. Coordinated with Afghan water agencies and involved NGOs; and,
10. Prepared a report summarizing findings, recommended actions and a prioritized plan to execute them.

1.4 Aquifer Analysis

CDM directed installation and testing of three new production wells and five test/observation wells (see **Figure 1.1**). Results showed the presence of three aquifers:

- Shallow Aquifer—sandy-layered unit, supplies water to low-yield wells, dry in most areas;
- Upper Aquifer—sand and gravel aquifer (observed occurrence between elevations of 970 and 960m) capable of good yields in some area; and,
- City Aquifer—sand and gravel aquifer) most productive aquifer tested, known occurrence between elevations of 950 and 900 m near center of town and slightly deeper eastward.

Just west of the center of town, the new PW 11 encountered metamorphic bedrock at an elevation of 875 m. The preliminary findings of this investigation suggest the aquifers may lie in a two or three-kilometer wide buried channel in or on-top-of bedrock that slopes eastward (and probably southward) from 900 m near the Gap to 850 m or less at Menzel Bagh.

Pumping tests at each new well indicate a combined (Upper and City) aquifer transmissivity of 200 to 500 m²/D (16,000 to 40,000 gpd/ft). Efficient wells in this aquifer would produce specific capacities of up to 4 L/s/m (20 gpm/ft) of drawdown. Current pumping rates of the CAWSS Operations Center wells (PW 1, PW 2, PW 3 and PW 4) cannot be measured but may be about 20 L/s (320 gpm) each. This is about 50% of their originally reported well yield that is assumed to have declined from 30 years of incrustant buildup and 10 to 20 m of water level decline. After one day of pumping, the cone of influence around each new production well has an estimated radius of at least 500 m, which means that CAWSS Operations Center production wells all interfere with each other, lowering water levels 2 to 6

meters in addition to their own pumping drawdown. During the 24- to 36-hour pumping tests on the new wells, cones of influence did not stabilize – indicating interference between wells and the radii of influence will continue to expand with extended pumping. **Figure 1.2** shows that overlapping cones in the area of PW 1, 2, 3, and 4 have created a significant depression in the groundwater table. CAWSS should attempt to distribute withdrawals more evenly over the city. New PW 12 and 13 and the new well at Qalacha developed by the International Committee of the Red Cross (ICRC) may begin to relieve some of the local overdraft. CDM's preliminary water level data, in **Figure 1.2** also shows groundwater movement southward away from the Lo Walla Canal funneling toward the induced pumping depression at CAWSS Operations Center.

1.5 Water Quality

Laboratory analyses of water samples from project wells PW 12 and 13 and TW 1, 2, and 3 indicate moderately hard water (average Ca + Mg = 100 mg/L) and high salinity (TDS = 1,000 mg/L). The water is scale-forming, and incrustants have and will continue to block well screen openings. New data also suggest increasing salinity from west to east, and water temperatures (20° C) that seem five to ten degrees cooler than expected. (Natural groundwater temperature should approximate the mean annual temperature that in Kandahar is assumed to be higher than 20° C). Canal water from the Arghandab has TDS of about 350 mg/L. As water moves through the ground, it dissolves minerals increasing its salinity. Data from local wells suggest salinity may have increased 20% or more since the early 1970s.

1.6 Recharge

All available information strongly suggests the primary source of recharge to the aquifers is leakage from canals. Supporting factors include:

1. Recharge from infiltrating precipitation would be very limited (at best);

2. Leakage of 25% of flow from unlined canals is not unusual;
3. Recent rapid groundwater decline coincides with extended absence of canal waters;
4. Groundwater gradients show movement of water southward from the main canal and toward the center of pumping;
5. Water quality characteristics support canal leakage– particularly on the Kandahar side of the Lo Walla Canal;
6. When the main canal carries water and lost as little as 5% of the flow, at least 10,000 m³/D (4.4cfs) would infiltrate to local ground water;
7. Canal leakage of 10,000 m³/D would sustain CAWSS and other local withdrawals and maintain high groundwater levels; and,
8. When canals are empty, local pumping would cause the sharp declines in local groundwater levels.

1.7 Recommendations

- Improve wells to protect against potential contamination sources and enable discharge-rate and water-level measurement;
- Develop a monitoring program – essential to increasing reliability and providing critical data to begin managing the resource;
- Survey the reservoir behind Dullah Dam to determine if 50 years of siltation has filled it so that remaining capacity is not adequate to maintain water in the river and canal; and,
- Develop supply wells in the Arghandab River Valley and pipe this higher quality water to the city to ensure a safe, drought-proof supply that, during periods of surplus flow, could be used to artificially recharge the Kandahar basin aquifers.

Section 2

Data Sources

2.1 Summary

Our team found a miniscule amount of existing information describing local groundwater, and the little available was from the pre-war era. During their occupation, the Soviets collected some water resource data but this information was not preserved or shared. The Taliban eliminated whatever water resource data they found. As a matter of practice, local well drillers make no written record of completed wells and this paper-saving practice appears unlikely to change in the near future.

CDM identified only two reports describing hydrogeologic conditions in Kandahar – one by the USGS in 1971, the other by the Danish Committee for Aid to Afghan Refugees in 2000 (DACAAR 2000). One additional report by Norwegian Church Aid–Afghanistan Program (NCAAP 2002) reviewed groundwater conditions for Afghanistan with a brief section on Kandahar.

ICRC recently compiled available information describing Kandahar’s CAWSS wells and made those data readily available to the team. UNHCR compiled data on some of the hundreds of recently drilled, small-diameter wells in the area. However, with few exceptions, the hundreds (perhaps thousands) of NGO wells completed since 2001 are completed without a well log or any record of water level, yield or water quality.

We describe in this section the hydrogeologic setting of Kandahar, our approach to the project, data gaps and initial data collection.

2.2 Hydrogeologic Setting

The City of Kandahar occupies a broad, flat plain at an elevation of about 1,000m in southwest Afghanistan. The city extends about 14 km (east to west) and 5 km (north to south) near latitude 31.6N and longitude 65.7E.

On the west side of the city two high bedrock ridges rise sharply to more than 500 m above the plain. These steep ridges are about one-kilometer wide at the base and extend northeast–southwest for tens of kilometers. The ridges are composed of nearly vertically dipping limestone (probably with some dolomite), a few thin shale units and a meta-igneous core. The flanks and top of the ridges have weathered into sharp irregular features and are pocked with crevices and small caves. On the west end of the city, the bedrock ridge has been offset by a right-slip transverse fault creating an erosional gap, here called “the Gap,” about 2km wide, also shown in **Figure 1.1**.

The Arghandab River channel is about three or four kilometers west of the Gap. This is the only significant surface watercourse in the area. In the early 1950s, the US Bureau of Reclamation (USBR) constructed the Dallah Dam about 40km upstream. The dam controls the flow of the River at a reported average annual discharge of 40 m³/sec (USGS 1971). However, in November 2002, except for one small pond, the river was totally dry. The river channel itself is at least 2km wide and floored with cobble-sized gravels.

Beginning centuries ago, the Kandaharians built and used canals to direct water from the river, through the Gap and onto the Kandahar plain. The canals provided water for irrigating productive orchards, vineyards and vegetable gardens. Historically (and even today) the canals also provide some domestic water. More recently the USBR constructed a major canal, the Lo Walla Canal, to deliver water from the Arghandab River, through a tunnel (about 3km north of the gap) and 15 or more kilometers through central Kandahar. Except for a few short concrete-lined sections at major diversion points, the Lo Walla Canal and the historic canals are unlined over their full reach.

The USGS noted the average annual precipitation declined from 178 mm (1940-1960) to 141 mm (1963-1970). There are no precipitation data for the more recent period, but reliable sources confirm there has been no rain for three years. At the same time, average temperatures seem to be increasing (9.2 to 10.50 C between 1963 and 1970). The USGS calculated local evapotranspiration (mostly evaporation) at 1700 mm, or at least ten times the available precipitation. These climatic factors virtually preclude the possibility of groundwater recharge from infiltration of precipitation.

Investigations conducted by the USBR indicate the upper 3 to 4 meters of surface sediments of the Kandahar Plain are relatively permeable (7.4 m/D). This combination, of unlined canals and permeable surface sediments, could easily allow substantial quantities of water to seep out of the canals and infiltrate the adjacent sediments.

The impacts of five years of sustained drought are apparent on the local trees, orchards and vineyards. In the city, large trees (at least 50-years old) are nearly all dead or dying. West of town, many well-established orchards and vineyards are dead and have been cut down. The only orchards able to sustain life are those that have the benefit of irrigation from deep wells.

The few well logs available indicate cemented and compact sediments (clay, sand and gravel) underlie the city to a depth of at least 100m. Drilling conducted as part of this program encountered (water-bearing) bedrock at a depth of 60m at the north side of the gap, green-black bedrock at 90m about 4 km northeast of the city, and black (phyllite) bedrock near the center of town at 150 m. The maximum known thickness of sediments in the center of the basin is at least 180 m (deep well log in east Kandahar) and could be as deep as 300 to 400 m in some parts of the basin.

Numerous shallow water supply wells penetrate the sediments to depths ranging from 10m to

30m. During the recent drought, NGOs and private parties have drilled hundreds of new wells in the immediate area of Kandahar and thousands of wells in the Province. As a result of the drought, many shallow wells (less than 15 to 20 m) have gone dry.

The largest groundwater producer in the area is CAWSS – City of Kandahar water supply system. ICRC (June 2002) reported that only five of the nine CAWSS wells were in operating condition and connected to the system. CAWSS operates the five wells 2 to 7.5 hours per day to produce 3,158 m³/D (average 36 L/s). There are also some groundwater withdrawals for irrigation in the area, but crop sizes are limited and well yields are relatively small (less than 10 L/s). Most of the thousands of small diameter wells drilled since 2001 have been equipped with UN-type hand pumps and even the strongest can pump only 1 L/s or less.

2.3 Approach

In late summer of 2002, CDM contacted CAWSS officials, UN agencies and others engaged in water development and management in Kandahar. In late October, the groundwater team assembled in Kandahar, renewed those contacts and discussed project plans, including drilling, testing, monitoring and data collection.

CDM hired two local engineers, Sr. Eng. Abdul Rahman and Eng. Rahmat Gul, and professional geologist Yar Mohammad, who was responsible for drilling and logging. Rahman directed engineering support. During the three-week period CDM's lead hydrogeologist was in Kandahar, the team conducted daily training in modern aspects of well design, construction, logging, aquifer testing, water quality sampling protocol and analysis, resource monitoring and data collection/compilation. CDM provided a portable electric logging system (Keck-DR). Jean Daniel Cavin (SDC), UNHCR, assisted the local crew in operation of electric logging equipment. The team also prepared test and production well drilling, construction, development and testing

specifications for each type of well and equipment to be used on the project.

After Nov. 4, 2002 CDM's local crew carried out all onsite drilling, testing and monitoring and transmitted data to Carr and Choquette for this report. The in-country crew successfully constructed and tested eight 100- to 150-meter wells in this seven-month period – a significant accomplishment. These professionally logged wells with comprehensive pumping tests and water quality analyses provide a significant first step in understanding the area's groundwater resources.

2.4 Data Gaps

As noted above only three reports with information on local hydrogeology have been identified, and comprehensive logs from pre-existing wells are extremely rare. The USGS report does provide logs of some sixty shallow-augured holes averaging about 15m in depth over 1,500 square kilometers of the Province of Kandahar. It also mentions the results of one pumping test on a pond and a second test at the Silo Well (10 km west of Kandahar).

The DACAAR report (2000) addresses groundwater throughout the province and does not provide much data on groundwater in or near the city of Kandahar. It does list details of the German Technical School well drilled in 1968 to 49 m with a sand and gravel aquifer between 29 and 46 meters, completed with wooden casing and screen. CAWSS operates a PW – 1 at the German Technical School, but the wooden well must have been replaced. Several other wells listed could also be those the CAWSS now operates (or near those wells) but good map locations and detailed site descriptions are not provided.

Perhaps the most frustrating aspect of the abundant data gaps was the unavailability of an adequate topographic map of the area. For this

report, CDM elected to use the September 2002 UNOCHA (de) Mine Action Program for Afghanistan. This Russian-prepared map has vague contours at 10-meter intervals. Correct elevations are critical to evaluation of water table gradients.

CDM used a hand-held GPS system to help identify the location and elevation of each new well drilled as part of this project. The readings are believed to be reasonably accurate regarding latitude and longitude, but the recorded elevations are frequently questionable.

Historic water quality data are even more rare than well log or other hydrologic data. The USGS report provides values for total dissolved solids for several wells in or near Kandahar and mentions analyses for seven major cations – but the data are not included.

Finally, basic precipitation records were found to be absent or incomplete and only one stream discharge estimate of the Arghandab River was located (USGS 1971).

2.5 Initial Data Collection

The well logs, pumping test results, and water quality data recorded as part of this project provide an important first step in obtaining sufficient data to make definitive conclusions about the resource.

CDM also initiated a water-level monitoring network. Monitoring of these should be continued on a monthly or more frequent basis. Most of these wells are near the center of Kandahar and more wells from the area should be added to the monitoring network.

Local designers of new production wells can use this start as a template and make data publicly available. CAWSS or the UN Area Coordination Office could act as repository for groundwater and water resource data.

Section 3

Monitoring Program

CDM established a water-level/water-quality monitoring program in October 2002 to begin evaluation of groundwater resources.

3.1 Existing Wells

The initial monitoring effort attempted to identify, locate and measure wells described in the USGS and DACAAR reports. This effort was only partially successful because the reports did not describe identifiable locations, or the listed wells had been destroyed. In virtually all City production wells, pumping equipment blocked access for water-level measurement and a few of previously studied wells were found to be dry.

The team was unable to measure water levels in any city production well because submersible pump-drop pipes blocked sounder access to the water level. The 6-inch drop pipes all have flanged connections – about ½-inch diameter smaller than the well casing inside diameter. Flanged connections are used because threads available on larger diameter steel pipe lack sufficient strength to hold the weight of the pump and pipe. City production wells also are not equipped with any sort of flow meter and, with the inability to measure water levels, direct evaluation of current performance of each production well was not possible.

The team also canvassed selected areas to identify additional existing wells suitable for water level measurement, water quality sampling and monitoring. **Table 3.1** lists wells identified and located and identifies data that are reported (R), estimated (E) and unknown (X). Data not followed by R, E, or X were collected by direct measurement with an electronic water-level sounder. CDM determined and checked well locations and elevations of ground surface at the well using a GPS instrument. Elevations are listed as estimated (E) and may be more than 2 or 3 meters in error.

3.2 Long-Term Water Level Change

Table 3.2 lists known wells where water levels could be measured and historic water levels are available from USGS and DACAAR reports, with the assumed year of data collection. CDM collected current static water level in early 2003. Changes at the Silo and Spozmey Hotel wells are estimated from adjacent wells (Silo well was not measurable, and Spozmey Hotel well had been bombed out). In 1971, the USGS report noted, the Kandahar area was suffering severe drought and groundwater levels were much lower than normal. Current water levels, therefore, reflect a very serious decline over the last 30 years. In these data, the greatest decline is at PW 4 or near the center of town, near where CAWSS makes its primary withdrawals.

3.3 Short-Term Water Level Change

CDM staff initiated water level monitoring in some existing local wells in October 2002. As new wells were completed, new monitoring points were added to the network. **Table 3.3** lists the available water level data. Interpretation to evaluate seasonal water level change is difficult, because local pumping impacts water levels in many of the wells. Interference from nearby pumping is obvious in water levels measured at TW 2 (TW 6) and K 12 (Menzel Bagh). The least impacted water levels are probably those at K 5 (Men's Hospital), K 6 (Silo) and perhaps K 17 (Kulle Urdu Army Base). At the Men's Hospital well, water levels dropped more than two meters in two months (March to May, 2003). This may reflect pumping from City Production wells near the CAWSS Operations Center.

The Silo well is located about 10 Km west of the City in the Arghandab River drainage. In October 2002, this 17-meter-deep dug well was dry at a measured depth of 17.14 m. The March 15 measurement of 22.47 m is probably an error and may have been reported as depth below the

top of the stone well casing instead of ground surface; in May, water levels rose more than two meters, perhaps reflecting the reappearance of water in the Arghandab in April 2003. Between November 2002 and May 1, 2003, the measured decline in water levels in K 17 (Kulle Urdu Army) was more than four meters. By May 15, only two weeks later, the measured water level was two meters higher. This rapid rise may have resulted from the return of water to the Lo Walla Canal on April 25. The USGS report (1971) noted that near irrigated fields, groundwater levels fluctuated about 1 meter annually in response to irrigation. Seasonal groundwater fluctuations were absent in non-irrigated areas. During the recent 3-year drought, with virtually no water in the canals, irrigation has been limited to private wells and is much reduced. The long-term water-level decline clearly has exceeded the amplitude of likely seasonal fluctuations.

3.4 Existing Water Quality

CDM collected water samples at selected monitoring wells for analyses of field

parameters (pH, chloride, nitrate and iron). CDM analyzed the samples using Hach Field Test kits. In some samples, specific conductance was noted to increase during while the analysis was being conducted. The cause of this change is outside the scope of this investigation. **Table 3.4** lists results of sample analysis of local wells.

3.5 Changes in Water Quality

Very few previous water quality data are available. The USGS report presented some analyses for total dissolved solids (TDS) from wells within the city. The DACAAR report (2000) includes some more complete analyses, but all results are for dug wells outside the immediate area of the city. TDS in mg/L can be calculated as 0.67 times the specific conductance in micromhos/cm (umhos/cm). Using this relationship and 1971 TDS values for wells at CAWSS Operations Center (PW 1, TW 1) it appears TDS may have increased about 1/3 (33%) over 30 years at this location. Regular sampling and analysis of specific conductance are needed to further evaluate long-term change.

Table 3.1 Existing Wells

CDM #	Well Name	LAT (N)	LON (E)	Elevation (m)	Dia. (inches)	Depth (m)	SWL (m)
K1	Qalacha new City Well (ICRC)	31.63.30E	65.67.40E	1020E	8	70.0	17R
K2	Kishki-US Army	31.66.00E	65.67.60E	1080E	18	80.0	dry
K3	Swimming Pool	31.62.952	65.66.667	1015E	8	70R	12.00
K4	PW1 Mech. Lycee	31.61.50E	65.69.00E	1006E	10	90R	29R
K5	Men's Hospital	31.61.30E	65.69.70E	1008E	8	48R	17.40
K6	Silo Dug Well	10 km w of	Kandahar	1000E	30	17.14	Dry
K7	Faisal K. Elem. Sch.	31.61.868	65.67.365	1021M	8	27.0	20.78
K8	Haji Sadar Moham N	31.61.82E	65.65.12E	1000E	10	38.0	10.38
K9	Haji Sadar Moham E	31.61.81E	65.65.11E	1000E	10	21.0	10.21
K10	Haji Sadar Moham W	31.61.80E	65.65.10E	1000E	10	33.0	10.47
K11	Kobi - Sayed K Shah	31.60.665	65.63.045	1010E	6	57R	17.68
K12	Menzel Bagh NE	31.62.00E	65.74.50E	1010E	16	60R	16.38
K13	Menzel Bagh NW	31.62.00E	65.74.40E	1011E	16	68.8N	17.08
K14	Menzel Bagh SW	31.62.95E	65.74.40E	1007E	12	180R	16.30
K15	NW well – USBR	31.61.30E	65.76.40E	1012E	6	16.1	10.70
K16	Raisin Factory	31.62.00E	65.76.60E	1012E	Dug/drilled	64R	>10R
K17	Kulle Urdu Army	31.6X E	65.6X E	1010E	12	X	X

Notes: R = Data are reported. E = Data are estimated. X = Data are unknown. N = K13, reportedly originally 180m and flowing artesian, now filled with rubble – SWL 17.08m

Table 3.2 Long-Term Water Level Change

Well #	Name	Year of Initial SWL	Current Year SWL	Elapsed Years	Decline in SWL (Meters)
K6	Silo Dug Well	1971	2003	32	6.2 E
K5	Men's Hospital	1971	2003	32	13.1
K14	Menzel Bagh SW	1971	2003	32	13.3
PW 4	German Technical School	1968	2003	35	19.9
PW 12	Mir Wais Lycee	1974	2003	29	8.3
NA	Spozmey Hotel (well bombed)	1971	2003	32	11 E

Table 3.3 Water Level Monitoring

Well #	Well Name	23-Oct	13-Nov	30-Nov	17-Feb	3-Mar	15-Mar	3-Apr	1-May	15-May
K 5	Men's Hospital	17.40	--	--	--	16.61	16.66	16.77	18.58	18.67
K-6	Silo	17.14 dry	--	--	--	--	22.47?	--	16.84	15.21
PW 12	Mir Wais Lycee	--	--	--	--	--	14.35	--	--	17.71
PW 13	Mah Bas Prison	--	--	--	--	--	13.84	--	--	--
TW 2	TW 6	--	--	--	22.15	27.7	23.91	--	--	--
TW 3	Sadat Ghundai	--	--	--	--	--	21.32	--	--	--
TW 4	Lo Walla	--	--	--	--	--	29.21	--	--	--
K 12	Menzel Bagh	--	16.1	16.1	13.63	--	15.35	15.92	--	--
K 17	Kulle Urdu Army	--	25.39	25.39	27.16	27.5	27.47	27.63	29.93	27.66

-- not measured

Table 3.4 Current Well Water Quality

CDM #	WELL NAME	DEPTH	DTW	Sp. Cnd.	pH	Chloride	Nitrate	Iron
		meters	meters	umhos/cm	#	mg/L	mg/L	mg/L
K3	Swimming Pool	70R	?	807	7.5	27	2	0
K4	PW 1 Mech. Lycee	90R	> 4R	255R	X	X	X	X
K5	Men's Hospital	48.0	17.4	616	7.7	X	X	X
K6	PW4 @ FKE School	81.0	X	No sample	X	X	X	X
K7	Faisal K. Elem. Sch.	27R	20.42	593	7.9	X	X	X
K8	Haji Sadar Moham N	38.0	10.38	1,528	7.3	X	X	X
K9	Haji Sadar Moham E	21.0	10.21	1,425	7.5	30	2	0.15
K10	Haji Sadar Moham W	33.0	10.47	1,890	7.6	X	X	X
K11	Kobi	57.0	17.68	1,548	7.9	133	15	0.05
K12	Menzel Bagh NE	60R	16.38	1,785	8.2	208	5	0
K13	Menzel Bagh NW	68.8	17.08	X	X	X	X	X
K14	Menzel Bagh SW	180R	16.30	X	X	X	X	X
K15	NW well	16.1	10.70	X	X	X	X	X
K16	Raisin Factory	64R	>10R	1460	8	X	X	X

Notes: R = Data are reported. X = Unknown.

Section 4

Project Drilling and Testing

4.1 Drilling and Construction

CDM planned and directed installation of five test wells and three production wells for this project. CDM selected Khalid Sabawoon Engineering (KSE) to perform drilling and well construction. KSE provided direct rotary drilling equipment and crews, plus 3" and 6" diameter submersible pumps used during development and testing. KSE subcontracted percussion drilling to local contractors. CDM selected test well sites to provide maximum information to clarify existing conditions and help evaluate the future potential of the resource.

The project equipped three production wells with permanent high-capacity submersible pumps and CAWSS will operate these to provide additional water supply. Two test wells are inside the Operations Compound, near three large CAWSS Production Wells. These two test wells will be used as observation wells to monitor local water levels and the cone of influence around this groundwater production center.

Where hydrogeologic understanding was sufficient to preclude the need for test wells and CAWSS needed immediate additional supply CDM directed installation of production wells.

Rotary Drilling

Rotary drilling equipment was used on the larger diameter and deeper production wells – Mir Wais Lycee and Ahmad Shah Baba Lycee. Percussion equipment was used to drill and complete the 12-inch

diameter PVC, 60 meter well at Mah Bas Prison and the 6-inch PVC cased wells at CAWSS, Sadat Ghundai, Lo Walla and Haji Jamal Karz Lycee.

As prescribed by the specifications, rotary wells were first drilled 8-diameter and then reamed to 18-inch diameter. KSE circulated "natural mud" (mud created with fines encountered in the borehole) because higher grade drilling fluid was not available. On reaching completion depth (maximum 150 m), CDM evaluated formation samples and used manual multi-probe electric logging equipment (Keck DR) to evaluate the geologic section and confirm screen settings. Following logging, the contractor centered 12-inch diameter Grade D - PVC casing and vertical 0.060-inch (1.5 mm) slot PVC screens and packed the annular space with 5 to 10 mm gravel.

Percussion Drilling

Percussion drilling equipment is the most common method of well construction in Afghanistan, and is capable of penetrating up to 100 meters of unconsolidated sediments with 12-inch diameter hole. The method shares some

characteristics with cable-tool drilling, but the two are distinctly different. Local percussion drilling contractors first construct a tripod tower (from twelve or more, 2 meter lengths of flanged mild-steel pipe). The driller suspends a reinforced mild-steel bailer from the tower on left-lay cable (like the cable-tool drill stem cable) and passes the cable through a crown sheave to a ground-level cathead-like device powered by a gasoline engine. The driller works a shift lever to raise and drop the bailer (bit), chopping a hole through the



Percussion drilling rig

semi-consolidated sediments. At intervals, he uses the bailer to withdraw cuttings and slurry from the hole. The method is challenged where raveling sediments cause caving of the sidewall, and would probably not be very successful in drilling non-compacted or un-cemented sand, and alluvium.

Table 4.1¹ lists the drilling method used to drill and complete each well. The table also shows the diameter and total depth of the initial borehole in relation to the diameter and depth of the completed (cased) well. Each well was completed with a PVC cap on the bottom of short length of blank PVC casing below the deepest well screen. The blank casing acts as a sump during well development and allows the lower portion of the screen to be fully productive.

4.2 Well Locations and Design

Table 4.2 lists the eight wells completed for this project, showing CDM number, City number, latitude and longitude coordinates, elevation of the top of the completion casing, measured depth to water (DTW) below ground surface (bgs) after completion, elevation of static (non-pumping) water level, diameter of well casing, and well depth. The well locations were shown in Figure 1.1 (Section 1). **Figures 4.1** through **4.8** show graphic logs and completion designs of each well.

4.3 Pumping Test Results

On completion of each well, CDM directed 24-hour (or longer duration) pumping (aquifer) tests. The contractor used a 3-inch diameter submersible test pump to perform the aquifer tests in the 6-inch diameter wells and a 6-inch submersible pump in the 12-inch diameter production wells. CDM monitored discharge using an in-line water meter and measured water level drawdown with an electric sounder. Pumping tests were conducted at a constant discharge rate for 18 to 32 hours and water level

recovery after pumping stopped was monitored until the initial static water level was achieved or approached.

Test results (water level drawdown and recovery) of seven of the eight completed wells are illustrated in **Figures 4.9** through **4.15**. The upper part (A) of each figure illustrates drawdown and the lower (B) shows water level recovery after pumping stopped. No data are presented for TW 4 (Lo Walla) as no suitable aquifer was encountered at that location. The results indicate, pumping water levels in almost every well were impacted by pumping of other nearby wells:

- TW 1 (**Figure 4.9A**) shows 4 meters of interference after 1,000-minutes pumping. The outside pumping stopped 1,100 minutes into the TW 1 test and the pumping level recovered.
- At TW 2 (**Figure 4.10**) water levels recovered over one-meter after 30 minutes pumping, dropped sharply after 150 minutes, recovered and finally dropped about 1.5 meters near the end of the pumping test. The water level recovery (**Figure 4.10B**) shows outside pumping resuming after about 25 minutes of recovery. This interference is presumed to be from pumping of a CAWSS Production Well (probably PW1). The data can also be used to estimate a pumping rate of 20 L/s from the interfering source – or about 50% of its original (40 L/s) capacity.
- At TW 3 (Sadat Ghundai) there is no indication of outside interference and there are probably no operating wells in that area. The rapid response of the water level during initial recovery (**Figure 4.11**) verifies the relative inefficiency of this well.
- **Figure 4.12A** from Mir Wais Lycee (PW 12) records a total of 20-meters of drawdown. However, only 8 to 10 m of that drawdown result from pumping of PW 12 itself, the

¹ Tables and figures appear at end of Section 4.

other 10 m is from interference from pumping of other wells. Reportedly a nearby clinic and a carwash both operate independent well sources. The combined withdrawal of these two interfering wells could approach 30 L/s.

- **Figure 4.13A** shows at least 3 m of water level interference at PW 11, Ahmad Shah Baba Lycee. This interference may be from pumping of CAWSS PW 3 or another nearby high-capacity well.
- At PW 13 (Mah Bas Prison) about 0.5m of interference was recorded (**Figure 4.14**). This may be from a nearby well (K 3) used for irrigation and a swimming pool.
- AT TW 5 (Haji Karz Lycee) the pumping level nearly stabilized after 200 minutes pumping (**Figure 4.15A**) and fully recovered in less than 100 minutes (**Figure 4.15B**). No interference from outside sources was noted during the test period.

In several cases, (i.e. Mir Wais Lycee, Ahmad Shah Baba) interference from other wells is so great it masks the aquifer response to the pumping test. At these locations, estimates of aquifer transmissivity, specific capacity, and well efficiency are speculative. The results of testing are summarized in Table 4.3. The table lists static water level elevation, yield (Q – test rate in L/s); the drawdown (s) at rate Q in meters, the specific capacity (Q/s) in L/s/m, aquifer transmissivity and well efficiency.

Aquifer transmissivity (T) is a measure of the aquifer's ability to transmit water. It is the daily quantity of water that will pass through a one-meter wide strip of the aquifer under a one to one gradient. Transmissivity is also the product of the aquifer thickness and its permeability. Hydrogeologists calculate transmissivity from the response of the aquifer to pumping by measuring the in-well, water level drawdown and recovery; or from the water level drawdown

measured in neighboring wells within the pumping well's cone of influence.

CDM tested seven wells in Kandahar. The results listed in **Table 4.3** indicate aquifer transmissivity values between 200 and 1,500 m^2/D . The highest value at TW 3 at Sadat Ghundai may indicate very high permeability of the Gap gravels encountered between depths of 47.6 and 60 m, or a substantial contribution of groundwater from the underlying ten meters of limestone bedrock. In-town wells have moderate T values between 200 and 500 m^2/D . The variability in T from site to site could result from differences in cementation or the variations in grain size and sorting of the aquifer sediments.

Well Efficiency is critical to achieving optimum yield, operating economically and maintaining long-term performance. Inefficient wells have disappointing production, consume excessive amounts of electric power and become quickly scaled, further reducing production and shortening well life. In a 100% efficient, 12-inch diameter well (in a confined aquifer) the optimum specific capacity Q/s (after 24-hours continuous pumping) can be approximated from the relationship:

$$T/120 (m^2/d) = Q/s (L/s/m).$$

Then, actual specific capacity (Q/s) determined from pumping test data, divided by this theoretical 100% optimum specific capacity (Q/s) gives well efficiency.

CDM's Kandahar wells have efficiencies between 20 and 90%. Low well efficiency means the structure in some way limits the ability of water in the aquifer to enter the well. Efficiencies of 100% are never obtainable but 70 to 80% is usually achievable. Higher efficiencies in Kandahar wells might be achieved by:

- Using better quality drilling mud;
- Using better quality well screens with more open area;

- Tailoring gravel pack to sediments encountered at each well; and,
- Applying more exhaustive well development processes.

Even though pumping tests could not be performed on the city's existing supply wells, it seems unlikely their efficiencies could be much greater than 50%. Interpretation of data from TW 2 suggests efficiency at PW 1 may be 60% or less. Over time, the scale-forming tendency of the local water will incrust and partially close the screen openings. Incrustants also fill the pores of the gravel pack and aquifer next to the borehole. As time goes on, this plugging dramatically reduces the specific capacity, efficiency and well performance. Usually, careful redevelopment and rehabilitation can restore specific capacity and well yield to near original values.



Geologist Yar Mohammad collects samples for field analysis

4.4 Water Quality Results

During the pumping test of each well, water samples were collected for analysis of field parameters. CDM staff performed the analyses for specific conductance (Sp. Cnd.), pH, chloride, nitrate, iron and temperature using Hach Field test kits. Field analysis of pH and temperature provided actual ambient values. The staff noted that not only temperature but also pH and specific conductance of the Kandahar

groundwater samples often increased as the sample aged. Field analysis for iron reduces the possibility of bottle plating and provides more reliable results for non-acidified samples. **Table 4.4** presents the results of field analysis of project wells.

In April 2003, CDM re-sampled five of the new wells for full inorganic chemical analysis. Ken Choquette (CDM - Chief of Party) hand carried these five samples from Kandahar to the University of Iowa Hygienic Laboratory, Des Moines Iowa, USA². **Table 4.5** provides a summary of these laboratory certified analyses.

4.5 Permanent Pumps

USAID provided permanent pumps, electric motors, wire, controls and drop pipe for each of the production wells (plus spare parts). The pumps for PW 11, 12 and 13 are 6-inch, 40 horsepower (HP) FLOWLINE submersibles model 6FL-30/40-24ST.

Table 4.6 lists the pump parameters for each of the new production wells. All depth measurements are in meters below ground surface (BGS). The safe yield (Q) is the product of useable drawdown times the specific capacity. Here, useable drawdown is 50% or less of the total available drawdown (the vertical distance between the static level and top of the uppermost well screen). This design yield using only 50% of the total available drawdown provides a safety factor for interference between wells, a reduction in specific capacity at the higher pumping rates and a decline in well efficiency over time.

Table 4.7 lists the pump, recommended setting of the pump intake (BGS), and the anticipated discharge rate the pumping level in each well. The pump intake should be set above the uppermost screen in each well.

² The complete laboratory analyses and report are available from CDM upon request.

4.6 Wellhead Completion

Figure 4.16 illustrates the wellhead completion design installed at the six USAID - CDM observation wells and three production wells. These drawings, prepared by Hamidullah Bahloi (CDM Konduz), show a 10 cm thick reinforced 240 cm square well pad; and a 100 cm high 80cm

square pump base. The 16-inch production well casings were fitted with a flange and gasket to complete the surface seal. The six-inch observation well casings were fitted with a hinged, locking cap.

Table 4.1 Drilling Data

CDM #	CITY #	Well Name	Diameter Borehole (inches)	Diameter Cased hole (inches)	DEPTH drilled (m)	DEPTH completion (m)	Drilling Method
1	TW 1	CAWSS TW 1	10	6	98.5	95.5	percussion
2	TW 6	CAWSS TW 2	10	6	100.0	95.0	percussion
3	TW3	Sadat Ghundai	10	6	71.0	70.9	percussion
4	none	Lo Walla	10	6	95.0	95.0	percussion
5	?	Karz School	10	6	94.5	80.0	percussion
6	PW 12	Mir Wais Lycee	18	12	132.0	132.0	rotary
7	PW 11	Ahmad S B Lycee	18	12	150.0	145.0	rotary
8	PW 13	Mah Bas Prison	16	12	108.0	108.0	percussion

Notes: TW = Test/Observation Well. PW = Production Well. DEPTH drilled = total depth, i.e. below ground surface (bgs). DEPTH completion = depth to bottom of casing cap (bgs)

Table 4.2 Project Wells (drilled Dec 2002 – May 2003)

CDM #	CITY #	WELL NAME	LAT	LON	ELEV.	DTW	SWL - elev.	DIAM.	DEPTH
			N	E	meters	meters	Meters	inches	meters
1	TW 1	CAWSS TW 1	31.6130	65.6896	1006	19.0	987	6	95.5
2	TW 6	CAWSS TW 2	31.6138	65.6893	1007	21.8	985	6	95.0
3	TW3	Sadat Ghundai	31.6312	65.668	1021	22.0	999	6	67.0
4	TW4	Lo Walla	31.6534	65.7119	1066	29.3	1037	6	95.0
5	TW5	Haji Karz Lycee	31.5767	65.7232	995	11	984	6	94.5
6	12	Mir Wais Lycee	31.6209	65.73	1010	14.3	996	12	132.0
7	11	Ahmad S B Lycee	31.6118	65.689	1007	20.7	986	12	145.0
8	13	Mah Bas Prison	31.6180	65.667	1006	16.6	989	12	105.0

Note: Completion design for TW 5 (Haji Karz Lycee) was not available as of report date.

Table 4.3 Project Well Productivity

CDM #	WELL NAME	Screen	SWL-elev.	YIELD -Q	Dd -s	Q/S	Transm.	Well Eff
	Units	length m	meters	L/sec	meters	L/s/m	m ² /Day	%
1	CAWSS TW 1	36.6	987	9.2	5.5	1.67	300	70
2	CAWSS TW 2	39.0	985	9.3	4.0	2.33	500	55
3	Sadat Ghundai	27.0	999	9.2	3.8	2.40	1,500	20
4	Lo Walla	Not avail.	1037	No test	X	X	X	X
5	Haji J Karz Lycee	Not avail.	984	10	10	1.0	300	40
6	Mir Wais Lycee	51.0	996	13.9	10.6	1.74	330?	64?
7	Ahmad SB Lycee	23.0	986	9.0	3.9	2.3	300?	90?
8	Mah Bas Prison	45.2	989	9.4	7.3	1.29	300	50

Table 4.4 Field Analysis of Project Wells

CDM #	WELL NAME	DEPTH	SWL ELEV.	Sp. Cnd.	pH	Chloride	Nitrate	Iron	Temp.
	Units	meters	meters	umhos/cm	#	mg/L	mg/L	mg/L	C ^o
1	CAWSS TW 1	95.5	987	1,144	7.9	190	2	0	20
2	CAWSS TW 2	95.0	985	765	8.1	12.5	0.5	0	22
3	Sadat Ghundai	67.0	989	1,300	7.9	42	2	0	21
4	Lo Walla	95.0	1037	na	X	X	X	X	X
5	Karz School	94.5	984	1,850	7.8	208	0	0	19
6	Mir Wais Lycee	132.0	996	1,612	8.2	306	2	0.1	24
7	Ahmad S B Lycee	145.0	986	X	X	X	X	X	X
8	Mah Bas Prison	105.0	989	840	7.9	36	0.5	0	20

Table 4.5 Project Well Inorganic Chemical Analyses

ANALYTE	UNITS	NEW PW 13	NEW PW 12	CDM TW 3	CDM TW 1	CDM TW 2
Alkalinity-phen.	mg/L as CaCO ₃	<1.0	<1.0	<1.0	<1.0	<1.0
Arsenic	mg/L	0.001	<0.001	<0.001	0.001	0.001
Barium	mg/L	0.06	<0.05	<0.05	<0.05	0.06
Bicarbonate	mg/L	290	200	220	200	290
Cadmium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Calcium	mg/L	67	54	79	50	50
Carbonate	mg/L	0	0	0	0	0
Chloride	mg/L	31	300	44	340	17
Chromium	mg/L	<0.01	<0.01	<0.01	0.01	<0.01
Copper	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoride	mg/L	0.34	0.3	0.36	0.26	0.3
Hardness	mg/L	360	300	510	330	260
Iron	mg/L	<0.02	<0.02	<0.02	0.04	0.02
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Magnesium	mg/L	46	41	77	50	33
Manganese	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02
Mercury	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Nitrate as N	mg/L	2.8	1.1	2.9	2.5	1.9
pH	pH	7.9	7.9	7.9	7.8	8
Potassium	mg/L	3.5	2.6	2.6	2.9	1.7
Selenium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Silica	mg/L	25	15	21	14	24
Silver	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Sodium	mg/L	59	240	110	250	32
Spec. Cond.	umhos/cm	840	1600	1300	1800	580
Sulfate	mg/L	150	230	450	260	38
TDS	mg/L	560	1030	1020	1120	350
Total Alkalinity	mg/L as CaCO ₃	240	160	180	160	240
Zinc	mg/L	<0.02	<0.02	0.03	<0.02	0.05

Table 4.6 Pump Parameters

PW #	WELL NAME	SWL	Q/S	Available	Useable	Pumping	Safe Q
	Units	m - BGS	L/s/m	Dd - m	Dd - m	Lift - m	L/s
12	Mir Wais Lycee	14.3	1.74	26	13	27	23
11	Ahmad SB Lycee	20.7	2.3	45	20	34	46
13	Mah Bas Prison	16.6	1.29	27	13	30	17
							85

Note: m – BGS is meters below ground surface

Table 4.7 Pump Settings and Operation

PW #	WELL NAME	PUMP SETTING	PUMP	DISCHARGE	PUMPING LEVEL
		m - BGS	model	L/s	m - BGS
12	Mir Wais Lycee	35	6FL50/10-7	23	27
11	Ahmad S B Lycee	65	6FL50/40-24	46	34
13	Mah Bas Prison	40	6FL50/7.5-4	17	30

Note: m – BGS is meters below ground surface

Section 5

Interpretation of Results

Interpretation of the results of the groundwater investigations in Kandahar is based on very limited existing data and data from the drilling and testing of eight wells installed for this project. The interpretation is considered preliminary. New information from additional investigations and development and monitoring of the resource should refine and may even invalidate some of these interpretations.

5.1 Aquifer Characteristics

The interpretation presented here is based primarily on data gathered in drilling and evaluating samples from the eight wells drilled as part of this project. Clearly, logs from eight well sites cannot provide definitive information for such a large area. **Figure 5.1** illustrates west to east (upper figure) and north-to-south (lower) schematic cross sections based on data from the eight CDM wells. As shown, the basin is floored by bedrock (probably limestone in the west and metamorphic rock at PW 11). The floor of the basin deepens to the east and is filled with a greater thickness of more recent sediments.

The limited information indicates the sediments lie in a buried channel – with the deepest point (on the cross section) at PW 12. The channel rises sharply to the north and less steeply to the south. Within the basin channel are layers of compact clays (argillites), conglomerates, and sand and gravels generally having increased calcareous cementation with depth. The least-cemented sands and gravels are of course more permeable and are the most productive aquifer zones.

There appear to be two primary aquifer units:

- a relatively thin Upper Aquifer, generally present from a depth of 30 to 70 meters (elevation 970 to 930 m)

- a lower City Aquifer present between depths of 80 m and 140 m (elevation 930 to and 870 m).

At PW 11, the City Aquifer is over 50m thick but to the east a clayey argillite divides the unit into two zones - upper (a) and lower (b). However, the separation between the Upper and City Aquifers appears to be more continuous. At each of the logged wells, the Upper Aquifer is separated from the City Aquifer by a characteristic red to green colored clay – 10 m thick in the west and thickening to more than 30 m at PW 12.

Overlying the Upper Aquifer is a unit here called “Fanglomerate” – materials originally deposited in an alluvial fan and later consolidated or cemented. Drill cuttings from each site indicate the unit is composed of alternating layers of clay and cemented angular sand and gravel. When (and where) this upper unit is saturated, the more permeable sections were the target aquifer for most of the private and other shallow wells. When water levels were high, the yield of wells in the thin permeable zones of the Shallow Aquifer was sufficient to support hand-pump withdrawals.

At the Sadat Ghundai Well (the furthest west well drilled in this program), the water-bearing units are coarser, more permeable and at higher elevation. This suggests that an ancestral Arghandab River may have carried sand and gravels through the Gap and deposited the more permeable alluvial (stream) sediments in channels in the Kandahar Basin.

5.2 Recharge

Recharge is the most critical issue to sustain groundwater supplies in Kandahar. Recharge describes the process of how and how much water is taken into the subsurface. In general, precipitation falling on the surface runs off (as

surface water streams), evaporates, or infiltrates into the ground. The relationship is expressed most simply as:

$$R = P - ET - R_o$$

where:

- R = recharge
- P = precipitation
- ET = evapotranspiration
- R_o = runoff

The USGS (1971) reported that the average annual precipitation declined from 178 mm (1940-1960) to 141 mm (1963-1970). There are no precipitation data for the more recent period, but reliable sources confirm there has been no rain for three years.

At the same time, average annual temperatures seem to be increasing (9.2 to 10.50 C between 1963 and 1970). The USGS calculated local annual evapotranspiration (mostly evaporation) at 1700 mm or at least ten times the available precipitation. Analysis of the available precipitation data and calculated potential evaporation on a month by month basis further indicates there is no month when precipitation provides any excess (or water surplus) for runoff and infiltration. As shown in **Table 5.1**, even January - the wettest month historically, has an average 6mm deficit or shortage. However, rainfall that does occur is often torrential so that all of one month's precipitation may occur in one day or even a over a few hours. This type of precipitation typically runs off as sheet flow or in flood. The character of the shallow surface washes (stream channels) and nature of the surface sediments indicate catastrophic mudflows have occurred in the past.

Since average local precipitation does not appear capable of providing any significant quantity of recharge, some other source(s) must sustain the

area's groundwater resource. Cursory evaluation of local geology suggests high bedrock ridges formed from steeply dipping layers of limestone, shale and a metamorphic bedrock core would preclude subsurface inflow of water from any surrounding basin. Flood stage groundwater inflow from the Arghandab River through the Gap might be possible, if the elevation of the River ever exceeds 1010m. Normally River levels would be below elevation 990m in the area of the Gap.

Table 5.1 Water "Surplus" Calculations

Month	ET mm	Ppt mm	Surplus or Deficit mm
January	44	38	-6
February	65	34	-31
March	98	21	-77
April	166	18	-148
May	229	6	-223
June	256	0	-256
July	273	0	-273
August	260	0	-260
September	192	0	-192
October	28	2	-26
November	38	4	-34
December	49	24	-25
Annual Ave	1698	147	-1551

Notes:

ET = Pan evaporation at Menzel Bagh, (1937-1971, annual average); US Bur.Rec. 1970
Ppt = average annual precipitation Kandahar Airport, (1963-1970), Afghan Air Authority

The static water level elevation (999 m) at the Sadat Ghundai test well (TW 3) suggests the aquifer may receive some recharge from higher elevations on the ridge. The path and mechanism for such potential recharge has not been investigated.

Canal leakage is the most likely other source of "dependable" recharge to the local aquifer system. Many canals traverse the city and the Kandahar Plain. None of the canals are lined, and they only have silty-clay sediment sides and base. Some similar canals in the western United

States have documented losses of over 50% of the flow. The largest canal losses probably occur on the major Lo Walla Canal constructed in the 1950s. Northwest of town, this large canal is perhaps 10m (at the base), about 5m deep and 20m at the top. The canal originates below the Arghandab Dam, passes through a tunnel near latitude 35.647, longitude 65.671 and carries water eastward across the city 15 km toward the airport.

Historically, since its construction, the main canal carried water year-round (in most years). However, over the last few years there has been virtually no significant rainfall and the canal has carried water for only a few days. The lack of water in the major canal, smaller canals and diversions would curtail this source of groundwater recharge. As long as the canals are dry and local groundwater withdrawals continued, local water levels would continue to drop. The period of local water level decline and the drying-up of hundreds if not thousands of local shallow wells correlates with the period of waterless canals.

If canal losses average 5% of the probable flow, about 10,000 m³/D could easily infiltrate the subsurface. CAWSS withdraws about 5,000m³/D and other local groundwater users may withdraw a similar amount. During average precipitation years, canal losses could be roughly equivalent to the withdrawals and groundwater levels would be maintained. However, when the canals are dry over sustained periods, groundwater levels would decline rapidly.

Water quality differences also suggest canal leakage may be the primary source of recharge for the area (discussed in 5.5 Well Quality).

Kandahar saw some relief from the long-term drought during the first three months of 2003 (10 mm of rain fell in March). Water returned to the Arghandab River and to the Lo Walla Canal (at least temporarily) on April 25. The return of water to the canal and restoration of recharge

may be reflected in the water level rise in several observation wells (see Section 3.3 and Table 3.3).

5.3 Groundwater Gradient and Movement

This describes how groundwater moves after it has infiltrated the ground surface. The water level in each well completed in this program is at least 20m above the top of the Upper Aquifer indicating confined aquifer conditions. **Figure 1.2**, the map in Section 1, showed the surface of the “water table”. Water level elevations are highest in the west (999 m at Sadat Ghundai) and lowest near the center of the basin (985m at TW 2).

Under non-pumping conditions, a southerly or southwesterly component of groundwater movement could also be anticipated. Water infiltrating from the west-east supply canals (mostly on the northwest side of Kandahar) would migrate away from the source in all directions. Until the recent drought, groundwater levels were in fact very shallow south of the city and drainage canals were needed to prevent flooding and make the land useable. The area south of the city has been irrigated with water from numerous karezes. Most of these karezes and drainages were dry in late 2002.

Even with the limited available data, it is seems clear that groundwater funnels toward a depression in the area of CAWSS, as illustrated by **Figure 1.2**. This depression appears to be a result of major withdrawals from CAWSS Production Wells 1, 2, 3 and 4 located in this area.

5.4 Well Performance

The limited available data indicate the all existing CAWSS wells are completed in the Upper Aquifer (see Table 6.1). The production wells completed as part of this project (PW 11, 12 and 13) are screened in both the Upper and City Aquifers. This dual completion increases the potential yield and performance of the wells.

The optimum yield of a well is established by the transmitting capacity (transmissivity) of the aquifer(s), the available drawdown and well efficiency:

- Transmissivity is the product of aquifer thickness and permeability
- Available drawdown is the vertical distance between the static level and the usually the top of the uppermost well screen
- Well efficiency is a ratio of the well's actual specific capacity to the theoretical specific capacity determined from the transmissivity
- Specific capacity is the pumping rate (L/sec) a well yields per meter of drawdown or L/s/m.

An efficient well means that more water can be produced for any given amount of drawdown, reducing power consumption and extending the life of the well. In an inefficient well the pumping level inside the well casing is significantly below the water level immediately outside the casing. This usually occurs because the well screen and aquifer adjacent to the well have not been fully developed; or in older wells, the screen and aquifer have become clogged with incrustants which block flow into the well.

During these investigations, CDM staff was unable to measure static or pumpingwater levels in any of the city's existing production wells. In addition, none of the wells is equipped with a water meters or similar device and therefore the discharge rate could not be accurately determined. As a result, the specific capacity, well efficiency and possible need for redevelopment of the city's existing wells are all unknown. As described below (5.5 Water Quality), water quality analyses indicate the local groundwater is incrusting. This coupled with the age (30 years) of many of the city's wells suggests the wells would benefit from a thorough rehabilitation.

Pumping tests conducted at each new well indicate a combined (Upper and City) aquifer transmissivity of 200 to 500 m²/D (16,000 to 40,000 gpd/ft). Efficient wells in this aquifer would produce specific capacities of up to 4 L/s/m (20 gpm/ft) of drawdown. Current pumping rates of the CAWSS core wells (PW 1, PW 2, PW 3 and PW 4) cannot be measured but are probably 10 to 15 L/s (160 to 230 gpm) or about 50% of their originally reported well yield. We can assume the yields have declined from 30-years of incrustant buildup and 10 to 20 m of water level decline.

The pumping test results for Test Wells 1 and 2, Mir Wais Lycee and Ahmad Shah Baba Lycee (shown previously in **Figures 4.9, 4.10, 4.12, 4.13**) all indicate significant interference from other pumping wells. Pumping of PW 1, 2 or 3 causes mutual water level interference of two to three meters. The interference from each pumping well is additive on all wells within the cone of influence. During the 18 to 36-hour pumping tests CDM conducted on the new wells, the cones of influence did not stabilize - indicating interference between wells and the radii of influence will continue to expand over the pumping period.

At Mir Wais Lycee the combined interference inflicted by neighboring wells is greater than the well's own drawdown. Interference between wells greatly reduces the available drawdown and therefore well yield.

Based on the available test results, the cone of influence around each production well (after one-day of pumping) has an estimated radius of at least 500 m. This means that the CAWSS principal wells all interfere with each other lowering the water levels at least 2 to 3 meters in addition to the drawdown from their own pumping.

As shown in **Figure 1.2**, the overlapping cones in the area of PW 1, 2, 3, and 4, have created a significant and persistent depression in the groundwater table. Distributing the withdrawals

more evenly over the City will reduce interference and improve pumping yield. PW 12, PW 13 and ICRC's new well at Qalacha may help relieve the severity of the local overdraft.

CDM's preliminary water level data (**Figure 1.2**) also shows groundwater movement southward away from the Lo Walla Canal. The figure also clearly shows groundwater funneling toward the induced pumping depression near CAWSS Operations Center.

Long-term lowering of groundwater levels reduces the available drawdown and well yield. **Table 3.2** listed some historic and current water levels. These data show water levels in the city are at least 10 m lower now than they were in 1971. Water levels measured in 1971 were taken during a severe drought period. Water levels measured in wells in the area of CAWSS (Men's Hospital, German Technical School and Spozmey Hospital) appear to be 13 to nearly 20m lower than in 1971. If the CAWSS pumps have not been lowered since 1971 they could cavitate (apparent as air entrained in the water) and produce less water. Pumping under cavitation destroys pump bowls and can be prevented by reducing the pumping rate.

5.5 Water Quality

Comprehensive inorganic water quality analyses for five of the CDM wells are listed in **Table 4.5**. Field analyses of project wells are listed in Table 4.4 and field analyses of water samples from selected local wells are presented in **Table 3.4**.

Specific Conductance

Specific conductance (SPC) is easily (and accurately) measured in the field and indicates the ability of water to conduct electricity. As mineralization of the water increases it conducts more electric current, and therefore SPC is a measure of total dissolved solids (mineralization) of the water. (TDS in mg/L is about 2/3 of the value of SPC in umhos/cm.)

Field measurements of SPC show values between 593 umhos/cm at K 7 (near CAWSS PW 4) to 1,788 umhos/cm at well K 12 (Menzel Bagh Military Base) and 1,890 umhos/cm at K10. SPC at the US Military Base some 20 km east of town is reported to be over 2,000 umhos/cm. The base operates a reverse osmosis water treatment unit to make the water potable.

In general, SPC (and dissolved solids) increases from west to east across the city. There are however numerous contradictions to this generalization. For example SPC at CAWSS TW 2, about 100 m north of TW 1 was measured at 765 umhos/cm or about one-half of the value at TW 1. These differences could reflect variations in permeability of the aquifer at the sites where mineralization is lower in the more permeable sections of the aquifer. An increase in SPC from west to east also supports a westerly source of recharge – as from the Arghandab-fed canals. The USGS (1971) reported the SPC of the Arghandab River was 530 umhos/cm (350 mg/L TDS). CDM staff measured the SPC of the remaining pond in Arghandab River at 578 umhos/cm in early November 2002. Perhaps, water from the Lo Walla Canal, with low Arghandab mineralization, infiltrates more readily along the Canal's western reach and recharges the local groundwater. That infiltrated water then could move east and south increasing in mineralization along its path. The increase in specific conductance in the local groundwater over time appears significant and of concern. The three sites where reasonable comparisons of SPC can be made are summarized in Table 5.2.

Table 5.2 Increase in Specific Conductance

Well	CDM #	SPC		Increase
		1971	2003	
Units		umhos/cm	umhos/cm	umhos/cm (%)
PW 4	K 7	500	593	93 (19%)
Menzel Bagh	K 12	1400	1785	385 (28%)
Men's Hosp	K 5	530	616	86 (16%)

As water infiltrates, minerals are leached from the soil increasing total dissolved solids. Such increases can be particularly problematic in irrigated areas. The data in **Table 5.2** suggest SPC in Kandahar has increased about 20% over the last 30 years. Further evaluation of this potentially serious problem is beyond the scope of this initial investigation.

5.6 Other Parameters

Analyses of the parameters discussed below were summarized in **Table 4.5**

Nitrate is not normally a groundwater component that is derived from minerals in rocks. Rather nitrate in groundwater is generally an indication of contamination from agricultural sources or domestic wastewater. Analysis of samples collected during this project had concentrations of nitrate as nitrogen (NO₃ as N) between 1 and 5 mg/L. (One sample collected from a source 10 km southwest of the city (K 11 – Kobi) had a concentration of 15 mg/L –may reflect analytical error.)

PW 13 and TW 3 had NO₃ as N concentrations of 2.8 and 2.9 mg/L respectively. These wells, located west of the city, are in irrigated areas and the water quality may reflect some influence of the agricultural activity. These wells are also relatively near some of the older canals that have carried water from the Arghandab to the City for centuries. During reconnaissance of the area we noted that significant quantities of night soil from the city was stored very near these canals. Groundwater (and canal water) could be impacted by migration of nitrate (and other contaminants) from poor handling practices of these human wastes.

Iron is a frequent groundwater component that can impart taste, cause staining and foul system components. Groundwater in a reducing (lack of oxygen) environment can extract iron from minerals in rock and organic matter. CDM's analyses for iron in local groundwater indicate it is virtually not detectable - even at the low

laboratory detection limit of 0.02 mg/L. Iron is not expected to be a problem in local groundwater management and development. Manganese, a related metal is also at or below laboratory detection limit and should not be a problem.

Other Metals such as arsenic, lead and mercury can be a source of potential health problems in a public water supply. Concentrations of these metals in analyses of the five Kandahar samples show all of these metals to be at or below the laboratory detection limit. These metals will not be a concern in the Kandahar water supply.

Fluoride was found present at low levels (<0.4 mg/L) in each of the five full inorganic analyses conducted in this investigation. USEPA standards for fluoride are 1.4 to 2.4 mg/L, based on average annual air temperature. EPA assumes people consume more water in warmer weather and applies the 1.4 mg/L standard to those areas. Excess consumption of fluoride can cause mottling of the teeth and other health problems. At the low levels in the analyzed samples, fluoride should not be a local problem.

Chloride was identified in the five laboratory analyses at values from 17 to 340 mg/L. Chloride in an inland environment (distant from salt water sources) probably would not normally exceed 150 mg/L. The chloride values reported in Table 5.5 as PW 13 (31mg/L); TW 3 (30mg/L) and TW 2 (17 mg/L) probably represent the naturally occurring level of chloride in local groundwater. The elevated chloride levels at Mir Wais Lycee (PW 12) of 300 mg/L and at TW 1 of 340 mg/L suggest possible degradation of groundwater from local surface contaminants. The elevated sodium concentration at these two sites supports the possibility of potential degradation. As noted above, NO₃ as N and sodium is also highest in water from these two sites.

5.7 Corrosion and Incrustation

All water is either corrosive (capable of dissolving metals) or incrusting (capable of

forming scale). The pH provides a general indication of the tendency of water to corrode or incrust. Low pH values (less than 7.0) indicate water is acidic and corrosive whereas values over 7.0 indicate potentially incrusting water. The pH of all groundwater analyzed in Kandahar is well over 7 (as high as 8.2) so the water can be assumed to be incrusting.

Other chemical considerations, such as total dissolved solids, total (MO) alkalinity and calcium ion concentration also play into the corrosion/ incrustation potential. The Ryznar Stability Index (RSI) provides a means to make a more thorough evaluation of the corrosive and incrusting character of water based on these factors. **Table 5.3** is a spreadsheet used to calculate the RSI values based on for five the samples analyzed at the University of Iowa Hygienic Laboratory. The value of S in the table is calculated from TDS in mg/L and the value of

C is calculated from the relationship between total alkalinity and calcium ion concentration.

RSI values less than 7.0 indicate water is incrusting while values greater than 7.0 indicate the water is corrosive. The results listed in Table 5.3 indicate local ground water is generally incrusting. The values over 7.0 (suggesting corrosive water) at PW 12 and TW 1 may be related to the much-elevated values of sodium and chloride at these two sites (see Table 4.5).

Table 5.3 Ryznar Stability Index

sample	PW 13	PW 12	TW 3	TW 1	TW 2
TDS	560	1030	1020	1120	350
S	23.15	23.2	23.2	23.2	23.1
MO ALK	240	160	180	160	240
Ca	67	54	79	50	50
C	8.4	7.7	8.4	7.8	8.2
pH	7.9	8.2	7.9	8.2	8.1
RSI	6.85	7.3	6.9	7.21	6.81

Section 6

Other Factors

We describe here other factors relevant to the management and future development of the CAWSS Kandahar groundwater supply.

6.1 City Wells

Table 6.1 summarizes information from a June 2002 well summary (adapted from ICRC data). As shown, only five of the nine CAWSS wells were operating and connected to the system in June 2002.

The production (effective discharge) listed in the table is apparently based on the hours of operation and the original installed capacity of the well and pump.

The total daily production in June 2002 is reported as 3,158 cubic meters. Based on the limited hours of operation this is equivalent to a combined system total of 36.6 L/s.

Production is also limited by the lack of reliable electric power. The Kajakai Hydro Plant on the

Helmand River is currently only capable of providing about 30 MW during part of each day (six to ten hours).

CDM's observations made during October and November 2002 indicate the existing production well instantaneous discharge is substantially less than the original "effective discharge".

After 30 years of use and up to 20 meters of water level decline, it is unlikely that PW 1 and 2 produce at more than one-half of their original capacities.

Currently, none of the production wells is equipped with a water meter or has any reasonable means of measuring discharge. And, as previously discussed, static and pumping water levels cannot be accessed because of the large flanges on the pump drop pipe.

Table 6.1 City Well Summary (adapted from ICRC data)

Well #	Total Depth (meters)	Discharge Pipe Dia. (inches)	Year Installed/by	Reported Production m ³ /D / hours of operation	Comments
1	Unknown	5	1971/Japan	1042/7.5	"effective discharge."
2	Unknown	5	1971/Japan	862/7.5	"effective discharge."
3	57	5	2000/Habitat	324/2	"effective discharge."
4	57	5	2000/Habitat	0/0 (6/02)	Pump operating Oct. 2002
5	Unknown	5	2000/OWAAV	630/7	Near small reservoir
6	Unknown	5	2001/Taliban	0/0	Pump out June 02
7	67	5	2002/Habitat	0/0	Power station not connected June 02
8	57	5	2002/Habitat	0/0	Arcs clinic not connected June 02
9	50	5	1997/UNHCR-WFP	300/6	CDM # K12 operating Oct. 2002
			TOTAL	3158/36	Equivalent to 36.6 L/s

6.2 Optimum Well Yields

CDM installed three, 12-inch diameter production wells (PW 11, PW 12 and PW 13) and thoroughly tested the wells with 24-hour pumping tests monitoring discharge, drawdown and recovery after pumping stopped. Results show the new wells are about 50 to 80% efficient (that is they successfully produce 50 to 80% that a perfect 100% efficient well might produce).

These data also indicate the average specific capacity that could be expected from a well in central Kandahar (near CAWSS) is 2 or 3 L/sec/m. Using 10 meters of drawdown as a safe amount and, considering the observed interference between nearby wells, the optimum yield of PW 1, 2, 3 and 11 should not exceed 30 L/s.

Results from PW 13 (Mah Bas Prison) indicate an optimum yield of about 17 L/s.

Pumping test results at Mir Wais Lycee (PW12) indicate an optimum yield of 23 L/s. Interference from neighboring wells (clinic and carwash) greatly reduces the potential yield at this site.

6.3 Well and Site Protection

None of the observed CAWSS wells have effective caps or casing enclosures – rather rags and burlap have been wedged between the pump column (riser) and well casing. Also none of the sites have a defined protective radius and some of enclosures are open and have been used as public restrooms.

Hundreds of New Wells

The drought-induced need for water created a near-frenzy of well-intentioned drilling activity executed without understanding of local hydrogeology. Most of these wells (at least hundreds) have been equipped with UN hand pumps and produce relatively small quantities of water. Knowledgeable officials estimate that up to 75% of the recently drilled wells have gone dry – not as a result of over pumping, but from

the continuing decline of groundwater levels during the drought. Installation of these small-diameter, shallow wells is not only often fruitless but they also increase the potential avenues for surface contaminants to enter the subsurface.

6.4 Electrical Power Supply

Evaluation of the available power supply is beyond the scope of this report, except in consideration of how that supply impacts groundwater withdrawals. Kandahar's electrical supply from the Kajakai Hydro Power Plant is limited and unreliable – the power supply is often interrupted for relatively long periods. CAWSS normally operates the pumps from 6am to 1 or 2pm – also the likely period of highest water consumption. The new generator installed as part of CDM's Kandahar project will allow CAWSS to operate key pumps and maintain the water supply during power failures.

CAWSS is, and probably will continue to be, one of the largest power consumers in the city. The Kajakai plant and transmissions lines are in serious need of repair and upgrade to 130 MW to meet the existing power demands. The plant is located on the Helmand River about 100 km west of Kandahar. Other studies show the snow-fed Helmand River has the potential to provide substantially more hydro power. Additional power requirements of an Arghandab wellfield will require parallel improvements in power supply.

6.5 Dallah Dam and Reservoir

As described earlier, the primary source of recharge for Kandahar's groundwater system occurs as infiltrated losses from the canal system. In turn, the canals are fed water from the Arghandab River Dallah dam about 40 kilometers up-valley on the west side of the bedrock ridges. In relation to the Helmand drainage to the west, the Arghandab basin is relatively small and is recharged primarily by seasonal rains rather than snow as in the upper reaches of the Helmand.

For a variety of reasons, it seems likely the reservoir behind Dallah Dam may have become partially filled with sediments. The drainage basin above the dam has virtually no vegetation, precipitation events are intense and the dam and reservoir are about 50 years old. Siltation of the reservoir may be severely limiting the amount of water held in storage and reducing or displacing water that should be available for release to canals during dry months.

6.6 Finance

Financial issues facing CAWSS – Kandahar are also beyond the scope of this report, except as they impact groundwater use. It is our understanding the local CAWSS makes an annual charge of about US\$1 to each residential connection in the city. Further, there apparently is no effective means of uniformly collecting even this amount for water delivered.

The department has countless needs that require funding, including installation of new pipelines to connect new wells, replacement pumps and parts, service equipment, pipeline upgrades, new water storage facilities, engineering studies and continuing hydrogeologic work, salaries, etc. At the present time, CAWSS is reliant on donors and NGOs for its needs. To provide a reliable and safe water supply, CAWSS will soon need to establish a reasonable pricing structure and gradually develop economic independence.

6.7 Legal Issues

There do not appear to be any legal controls on groundwater development or use in the city or environs. Anyone with the funding can drill on his property (and perhaps on property owned by others or the government) to any depth in any manner and pump at any rate and quantity desired without regard to impacts.

The city is already experiencing interference from private wells at PWs 11, 12 and probably at other locations. Well completion methods are not controlled, allowing poorly constructed

wells to act as conduits for surface contaminants to move into the underlying aquifers.

In Kandahar, perhaps one quarter of domestic compounds have private wells (usually dug large diameter and unsealed). Cross connections in some homes probably allow domestic well water and water from other household sources to mingle with CAWSS water.

Some legal controls will be needed if the groundwater resource is to remain a safe source of public water supply in Kandahar.

6.8 Groundwater Outlook

The City of Kandahar has enjoyed an adequate groundwater supply for decades. The available information indicates the identified aquifers are recharged primarily by leakage from one major and a series of smaller unlined canals.

The supply has been adequate for two basic reasons:

- Water consumption for a city with a population approaching 500,000 is very low (perhaps 10 liters per person per day) or 5,000 m³/Day.
- When the canals are full, leakage is estimated to be at least 10,000 m³/Day.

When canal water is available to recharge local aquifers, the available groundwater probably exceeds the city's current water demand. However, over the last three years the canals have only carried water for two or three days. Thus current withdrawals have greatly exceeded the available recharge, causing water levels to drop precipitously (up to 20 meters lower than during the drought of 1971).

Possible remedies to this drought-induced water crisis include:

1. Importing groundwater from the Arghandab year round, and,

2. Developing deep, drought-resistant aquifers that may be present beneath the city.

Arghandab underflow could be extracted year round from wells completed in the river alluvium. When surface flow ceases, significant underflow continues. This underflow is judged to be at least two or three times Kandahar's anticipated future water needs. Two wellfields with 10 wells each capable of 50 to 60 L/s could be pumped to town through eight to ten miles of 24-inch (or larger diameter) pipeline. This would provide the city an adequate supply for the foreseeable future providing for both population growth and increased per capita demand. Water direct from the Arghandab would have much better quality (lower TDS) than that currently available from city wells where salinity may be increasing. During periods of low seasonal demand some of the Arghandab groundwater

could even be artificially recharged to the in-town aquifers increasing the reliability and quality of the supply.

Deep groundwater could be extracted from deep (200 to 500 m) wells in or south of the city boundaries. PW 11 encountered bedrock at 150 m but at Menzel Bagh (K-13) the well was terminated in unconsolidated sediments at a depth of 180m. The thickness of sediments overlying bedrock is unknown, but it is probably 200 to 400m or more south and east of town. From very limited data, bedrock appears to be higher both west and north of town. It is also possible that some of the underlying bedrock is cavernous (karst) limestone that could serve as a productive aquifer for the city. Such deep wells might produce 50 to 60 L/s each. The potential water quality from such deep aquifers is unknown.

Section 7

Conclusions

Our conclusions are based on review of a very limited amount of existing data and results of the drilling and testing completed as part of this program. Continuing evaluation of Kandahar's water resources will provide new insights that may alter or negate some of these conclusions.

7.1 Background

- Five years of continuous drought has dramatically lowered ground water levels in Kandahar causing many wells to go dry and creating a well-founded concern for the area's future water supply
- CAWSS provides water to the city's 500,000 residents from nine production wells
- Only a miniscule amount of data describing the local water resource, wells, water use and water quality exists
- This USAID sponsored project provides a first step in gaining understanding to sustain a reliable water supply for the area
- The City of Kandahar occupies a nearly flat basin at an elevation of about 1,000 meters. The basin is bounded on the west by a steep bedrock ridge with a 2-kilometer wide opening (the Gap) toward the Arghandab River Basin
- The Arghandab is the only significant stream in the area, and its flow is controlled by the USBR-built Dallah Dam
- The dam diverts water to a large, unlined irrigation canal that carries water through a tunnel cut in the ridge and across the Kandahar Plain
- Thirty years of reservoir siltation could be limiting the amount of water that can be held in storage, and restricting the release from Dallah Dam to the River and canal during the dry season

7.2 Groundwater Recharge

- Prior to the 1970s the average annual precipitation was about 141 mm (5.5 inches) per year
- Evaporation exceeds precipitation every month of the year and annual evapotranspiration is more than ten times the annual precipitation
- The combination of low precipitation and very high evapotranspiration rates provides little - if any - recharge to local groundwater
- Kandahar has suffered from severe drought over the last five years, and virtually no rain fell from 1999 through December 2002
- This near total lack of precipitation dried up the Arghandab River and curtailed flow of water in the canals
- The primary source of groundwater recharge in Kandahar appears to be leakage from the canals
- When water is present, canal leakage could easily exceed 10,000 m³/D
- Total groundwater withdrawals in Kandahar may be 10,000 m³/D
- Without canal recharge during the last three years, hundreds (perhaps thousands) of shallow (dug and drilled) wells in an around Kandahar have gone dry

- There are no records available of water level change in the City's (CAWSS) production wells (flanged pump columns prevent water level measurement)
- However, measurements from new test wells (observation wells) drilled in this program indicate water levels near the center of the City are now up to twenty meters lower than in December 1971

7.3 Drilling and Aquifer Designation

- As part of this program, the CDM team planned, designed, logged, directed installation, developed and tested three production wells (PW 11, 12, and 13) and five test wells (TWs 1, 2, 3, 4, and 5).
- We installed production wells where hydrogeologic understanding was sufficient to preclude the need for test wells and in areas where CAWSS needed immediate additional supply.
- We installed test wells at sites selected to provide critical information on the character and potential of the resource.
- Drilling has revealed three aquifers:
 - Shallow Aquifer – sand and clayey sands present between elevations of 1000 and 980 meters - once provided water to hundreds of shallow wells, now largely dry
 - a relatively thin Upper Aquifer, generally present from a depth of 30 to 70 meters (elevation 970 to 930 m)
 - a lower City Aquifer present between depths of 80 m and 140 m (elevation 930 to 870 m)
- Upper Aquifer – sand and gravel present between depths of 30 to 70 meters can provide significant quantities of water to larger wells. Most of the existing CAWSS wells are probably completed in this Upper Aquifer
- City Aquifer – major sand and gravel unit, present between depths of 80 to 140 m. The new production wells completed in this project are completed in both the Upper and City Aquifers. At several sites, a pervasive ten-meter thick unit of red/brown argillite (claystone) separates the Upper and City Aquifers
- The City Aquifer appears to thicken eastward toward Menzel Bagh where it is present down to a depth of 180 m. The most permeable and productive part of the aquifer system was found in the Gap at TW 3 (Sadat Ghundai)
- Drilling north of town at TW 4 (Lo Walla) did not encounter any significant water-bearing unit, and limestone bedrock at a depth of 93 m
- Drilling encountered bedrock (phyllite, metamorphic rock) at a depth of 150 m PW 11 (Ahmad Shah Baba Lycee)
- Drilling results indicate the City and perhaps Upper Aquifers lie in an east – west buried channel, that is perhaps about 2km wide (north to south)

7.4 Aquifer Test Results

- Pumping test results indicate the combined transmissivity of the City and Upper Aquifers is between 200 and 500 m³/D
- Wells with 100% efficiency, completed in these aquifers would have specific capacities of 1.7 to 4.2 L/s/m, and could produce 20 to 40 L/s depending on the useable available drawdown

- CDM tested PW 11, 12 and 13 at measured rates of 9.0, 9.4 and 13.9 L/s and calculated well efficiencies of 90%, 64% and 73% respectively
- It was not possible to determine the pumping rate, drawdown; or calculate specific capacity, transmissivity and well efficiency at any of the CAWSS operating wells
- The documented decline in water levels and the likely scaling of the well screens over 30-years of use can be assumed to have reduced the original yield (and initial yield of record) by 50% or more
- The total productivity of the CAWSS wells (prior to installation of the three USAID-CDM production wells described here) is estimated at 170 L/s or less
- Addition of 85 L/s from the new PWs 11, 12 and 13 increases the available supply about 50%

7.5 Water Quality

- Evaluation of field and laboratory analyses of water samples from wells drilled in this program shows local groundwater with these characteristics:

- Incrusting (scale forming)
 - High in total dissolved solids (TDS 500 to 1,000 mg/L)
 - Naturally occurring levels of chloride of 30 mg/L
 - Elevated in chloride (>300 mg/L) at two sites (PW 12 and TW 1)
 - Elevated sodium also occur at sites PW 12 and TW 1
 - Natural occurring levels of nitrate as nitrogen of 1.0 mg/L (well below the EPA standard of 10.0 mg/L)
 - Iron, manganese, arsenic and other metals at concentrations below the limit of laboratory detection
- Data also suggest TDS gradually increases from west (350 mg/L in Arghandab River) toward the east (1,200 mg/L at K 12)
 - Limited data indicate TDS may have increased 20% or more since 1970

Section 8

Recommendations

Numerous questions and issues still must be addressed to be able to sustain an adequate water supply for the City of Kandahar and environs. Our recommendations, listed in order of priority, are based on our current level of understanding. Understanding of the resource will improve and local needs and priorities will undoubtedly change as these recommendations and other actions are implemented.

8.1 Existing Production Wells

- Determine actual performance of each CAWSS production well – add totalizing water meters to the discharge line of each well and create access for water level measurements
- Perform a pumping test on each well to determine current yield, specific capacity, aquifer transmissivity and well efficiency
- Compare the current efficiency and well performance to the original reported yield
- Plan and execute well rehabilitation programs at each well with performance declines of 40% or more
- Install effective seals between the pump drop pipe and casing at each well

8.2 Define Canal Recharge Potential

- Install a line of three shallow (10 m) monitoring wells on each side of the Lo Walla Canal (30 m, 100 m and 200 m from the canal) at three locations (such as Qalacha, Ganj Earya, Khalil Mullah Alam)
- Monitor water levels, temperature and specific conductance in each monitoring well and the canal at least monthly

- Establish a canal flow monitoring program to measure canal flow at a minimum of three locations
- Compile rate and quantity of diversions between monitoring points
- Evaluate data to determine canal losses, gradient away from this recharge source and changes in the water quality

8.3 Explore for Sustainable Supply in Arghandab River Valley

- Drill, develop and perform pumping tests at potentially productive groundwater sites in Arghandab River Valley, such as:
 - Lat 31.63; Lon 65.64
 - Lat 31.68; Lon 65.63
 - Lat 31.70; Lon 65.67
- Work at each location should include one 12”-inch diameter test production well 50 to 100m deep and at least two monitoring wells spaced at 50 and 100 m from the pumping well
- Pumping tests should be conducted at a continuous rate of 50 L/s or more for at least 72 hours
- Sample and analyze important water quality parameters throughout the test period
- Evaluate wellfield potential and plan future wellfield layout
- Evaluate potential pipeline routes between the wellfield and the City

8.4 Essential Monitoring

- Evaluate potential siltation of Dallah Reservoir
- Establish in-town weather station to record daily temperatures (max. - min.), daily precipitation, and wind
- Drill three new monitoring wells to a depth of 100m or bedrock at:
 - Lat 31.62; Lon 65.68
 - Lat 31.62; Lon 65.70
 - Lat 31.62; Lon 65.72
- Monitor water levels in these wells at least monthly
- Install at least one continuous water level recorder in CAWSS TW 2 (or TW 1)
- Continue water level monitoring in the well network established for this investigation
 - CAWSS TW 1
 - CAWSS TW 2
 - K 5, Men's Hospital (now de-mining HQ)
 - K 13 Menzel Bagh SW
 - K6 Silo dug well

- Establish a stream gaging station on the Arghandab River at the highway crossing
- Establish a gaging station in one or more prominent drainage channels

8.5 Resource Management

- Coordinate the monitoring and data collection programs
- Establish a database and compile incoming data
- Observe and collect records of all new wells drilled in Kandahar
- Canvass and record all existing (private, agricultural and public) groundwater pumping in or near the city
- Evaluate potential for artificial recharge of in-town aquifers with Arghandab groundwater (from new wellfield)
- Evaluate construction of spreading basins to capture and recharge seasonal excess of canal water (north of Qalacha)
- Evaluate construction of storm water collection basins in appropriate areas such as Lo Walla (Lat 31.65; Lon 65.70)

8.6 Power Supply

- Repair and upgrade the Kajakai Hydro Electric plant to 130 MW to meet the existing power demands

Section 9

References

1. Ground Water Reconnaissance in the Arghandab River Basin Near Kandahar, Afghanistan; USGS – Open File Report, December 1971
2. Ground Water Potential and Development of Water Supply Facilities in Kandahar Province, Afghanistan; DACARR July, 2000
3. Guidelines for Sustainable Use of Groundwater in Afghanistan, Norwegian Church Aid – Afghanistan Program (NCAAP), April 2002
4. City of Kandahar - Production Well data sets; ICRC, June 2002
5. Groundwater and Wells, Second edition 1986, Johnson Division, Fletcher Driscoll

Appendix A Kandahar Groundwater Study Scope of Work

Scope of Work

Afghan CDM/USAID WS& S Project

Groundwater Study in Kandahar, Afghanistan

October 8, 2002

Purpose:

To carry out a groundwater study that will provide a good understanding of the groundwater resources available currently and in future in and around Kandahar. Both water quantity and quality is to be addressed.

Summary of Approach:

The groundwater team will first collect and review all available reports and data on groundwater occurrence and development in the Kandahar area. This will delineate those areas where additional information is needed. The team will then collect additional field data by measuring groundwater levels, collecting and analyzing water samples, collecting soil samples during drilling operations, observing, measuring and sampling any local surface water and interviewing local drillers and groundwater experts. The team will use the opportunity of field data collection to establish protocols and train local engineers in the appropriate methods. The team will analyze the existing and newly collected data and prepare initial estimates of capability of the resource and identify water quality issues. The team will also consider possible means of improving well construction methods and the potential for enhancing the resource. This analysis will identify the critical data gaps. The information will be used to establish and prioritize a data collection program to help resolve those gaps. The team will use this analysis to plan an exploration, testing and development program. Finally the team will summarize the findings including maps and illustrations and provide conclusions and recommendations in a comprehensive report

Tasks:

1. Collect and review available technical documents, reports, maps and hydrological data. Identify in advance to country staff the equipment and other needs such as: drilling equipment, water quality testing and sampling equipment, geo-logging equipment / methods, pumps, flow meters, well “packers”, depth sounders, digital water pressure gages, etc. (Note: Items may have to be procured and transported from Pakistan or U.S.). This will be done before departure for Afghanistan.
2. Develop appropriate protocols for data collection, drilling and testing, water level and flow measurement and water quality analysis.
3. Collect additional new data in the form of:
 - a. Well logs
 - b. Current water levels
 - c. Water quality analysis
 - d. Hydrologic observations
 - e. Aquifer (pumping) tests
 - f. Local drilling and development methods

4. Create data base and compile existing and new data.
5. Train local engineers and technicians on hydro geologic data collection methods, monitoring and record keeping.
6. Analyze the available data to make preliminary estimates the potential of the resource.
7. Identify the data gaps and prioritize the data collection needs.
8. Identify and prioritize the opportunities for developing and improving local groundwater supplies.
9. Prepare a plan to execute the identified priorities
10. Coordinate with Afghan water agencies and involved NGOs.
11. Prepare a report summarizing the findings and recommended actions.

Implementation Team:

The team leader will be a senior hydrologist. The consultant should be a professional hydrogeologist with clear demonstrated ability to carry out the objectives. Background to include practical hands on field experience in all aspects including planning, developing study protocols, locating test well sites, designing test wells, well logging, and test well productivity. The consultant should also have considerable knowledge in water quality analysis, data and records management, training of local engineers and technicians and otherwise in executing groundwater development and drilling studies.

The CDM/Kabul Chief of Party (Ken Choquette) and Project Engineer (John Crippen) based in Kabul and local Kandahar office engineering staff will provide support and data collection completion follow-up, if necessary.

Period of performance:

Starting Date October 15, 2002 with completion April 2003. Hydrologist travels to Afghanistan and project cities for three-week period to include time in US for preparation.

Level of Effort (Estimate)		Schedule
1. Gather data before trip. Include, if at all possible, specifics of well drilling methods needed.	3 days	-
2. Travel to Kandahar directly. Meet CDM staff there)	2 days	Oct 15/16
3. Visit sites and meet with local hydrologists, drillers, and officials	2days	Oct 17/18
4. Develop study protocol, locate test sites Specify drilling equipment and drilling methods	5 days	Oct 19-24
5. Supervise, field study, collect data and train.	10 days	Oct 25-Nov 4

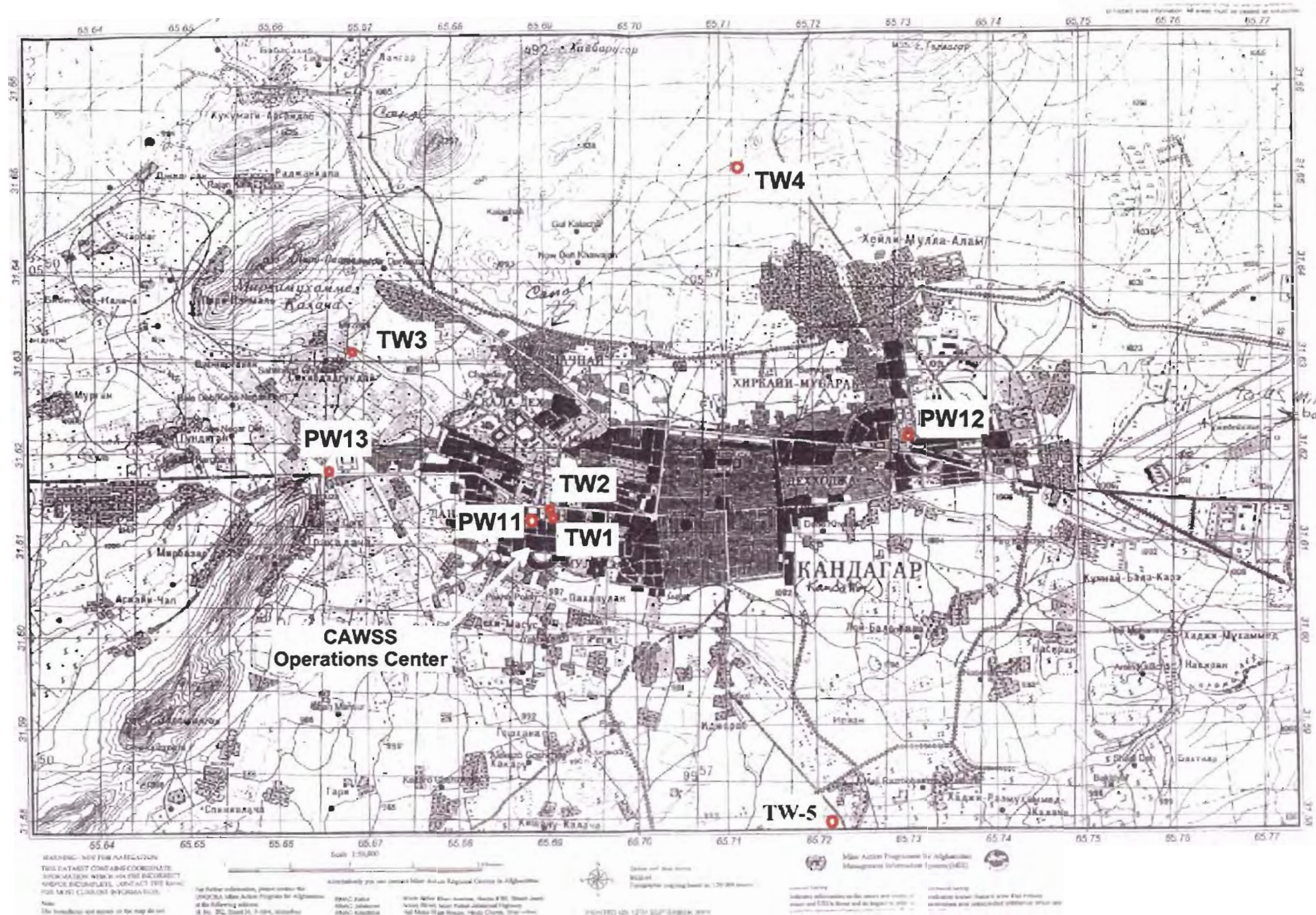
- | | |
|--|----------------------------|
| 6. Brief staff and prepare field report before leaving
with specific guidance for completing data collection. 1 day | Nov 5 |
| 7. Return to US | 2 days Nov 7 |
| 8. Analyze data and write report | 3 days complete by April 5 |

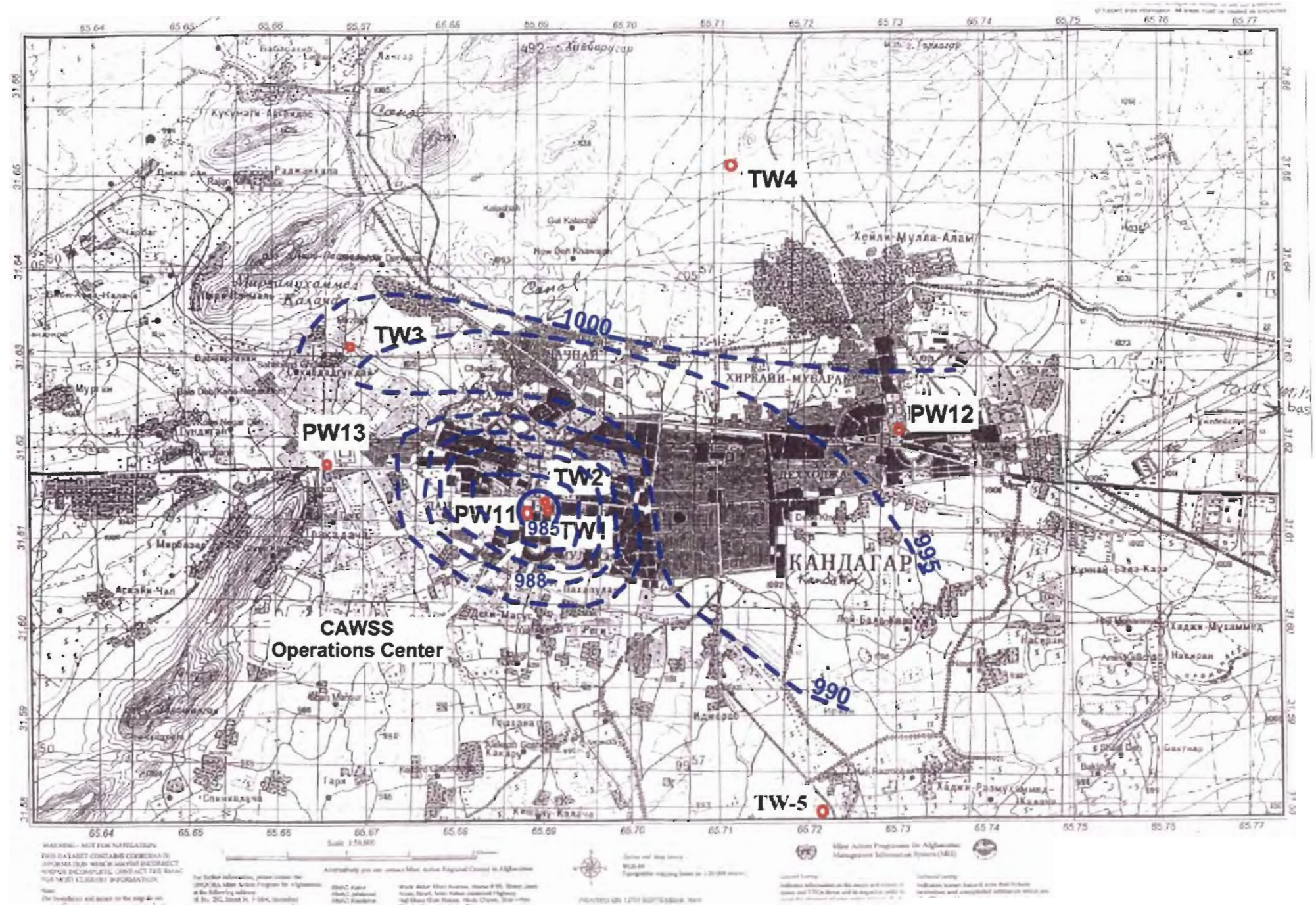
Final Product:

The final report should provide an understanding of the quantity and quality capacity of groundwater conditions at Kandahar City. The report should include specific recommendation on location of new well fields. The final report should have supporting analysis and specific recommendations. A suggested draft outline for the report is:

1. Executive Summary
2. Introduction
 - Background
 - Project Objectives
 - Description of the report
3. Methods and Approach
4. Findings
 - Geology
 - Hydrology
 - Water quality
5. Data Gaps
 - Identify
 - Methods to correct
 - Prioritize data collection plans
6. Analysis of the Resource
 - Groundwater occurrence
 - Aquifer recharge
 - Water quality issues and protection
 - Development potential
7. Priorities for future development
 - Exploration and testing program
 - Equipment and material needs
 - Priority areas for development
 - Resource enhancement potential
 - Training needs
8. Conclusions and Recommendations

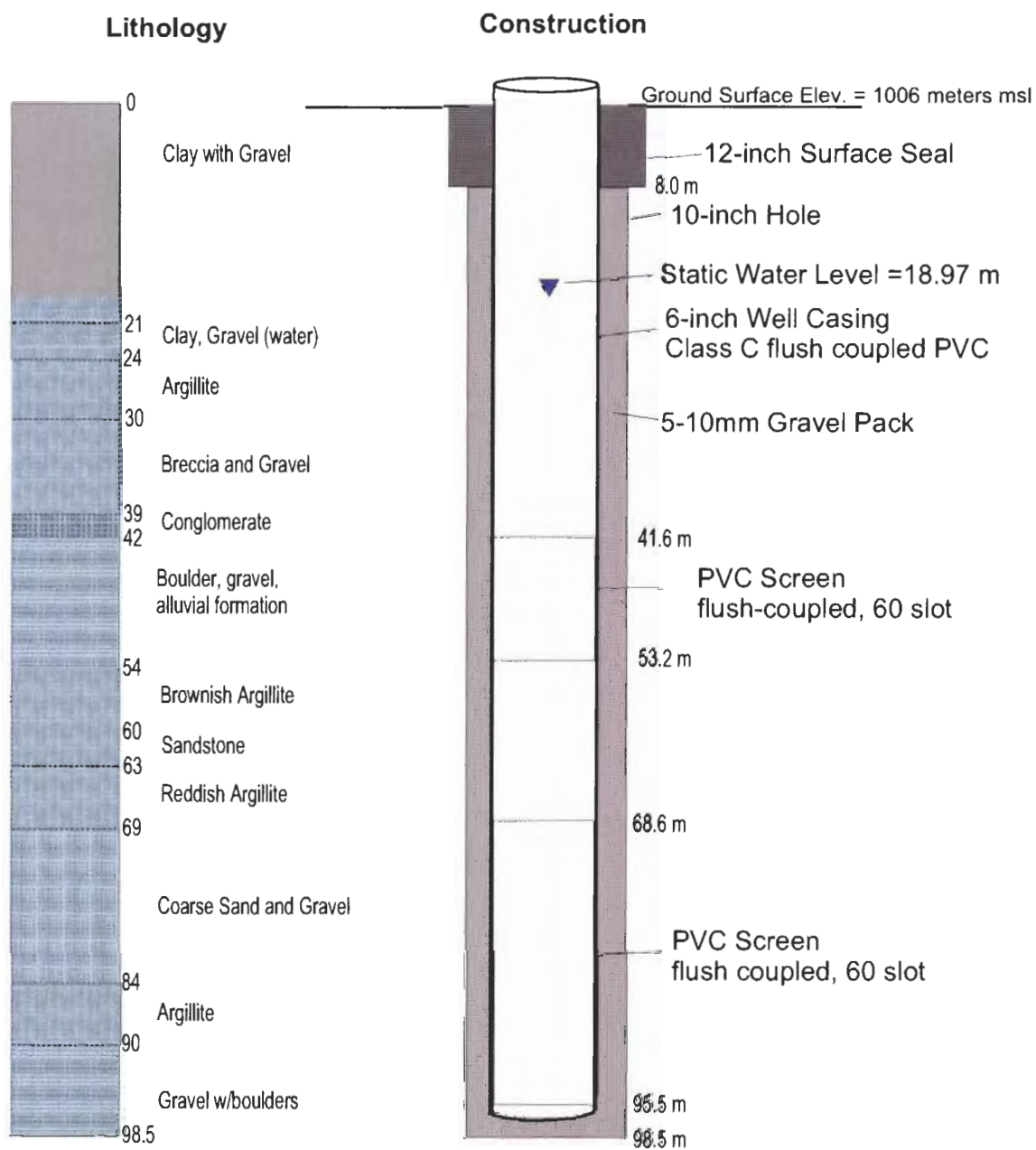
V:\ENG. IQC\Afghanistan WS&S assessment\SOW\Kandahar GW study SOW- October 8 2002.doc





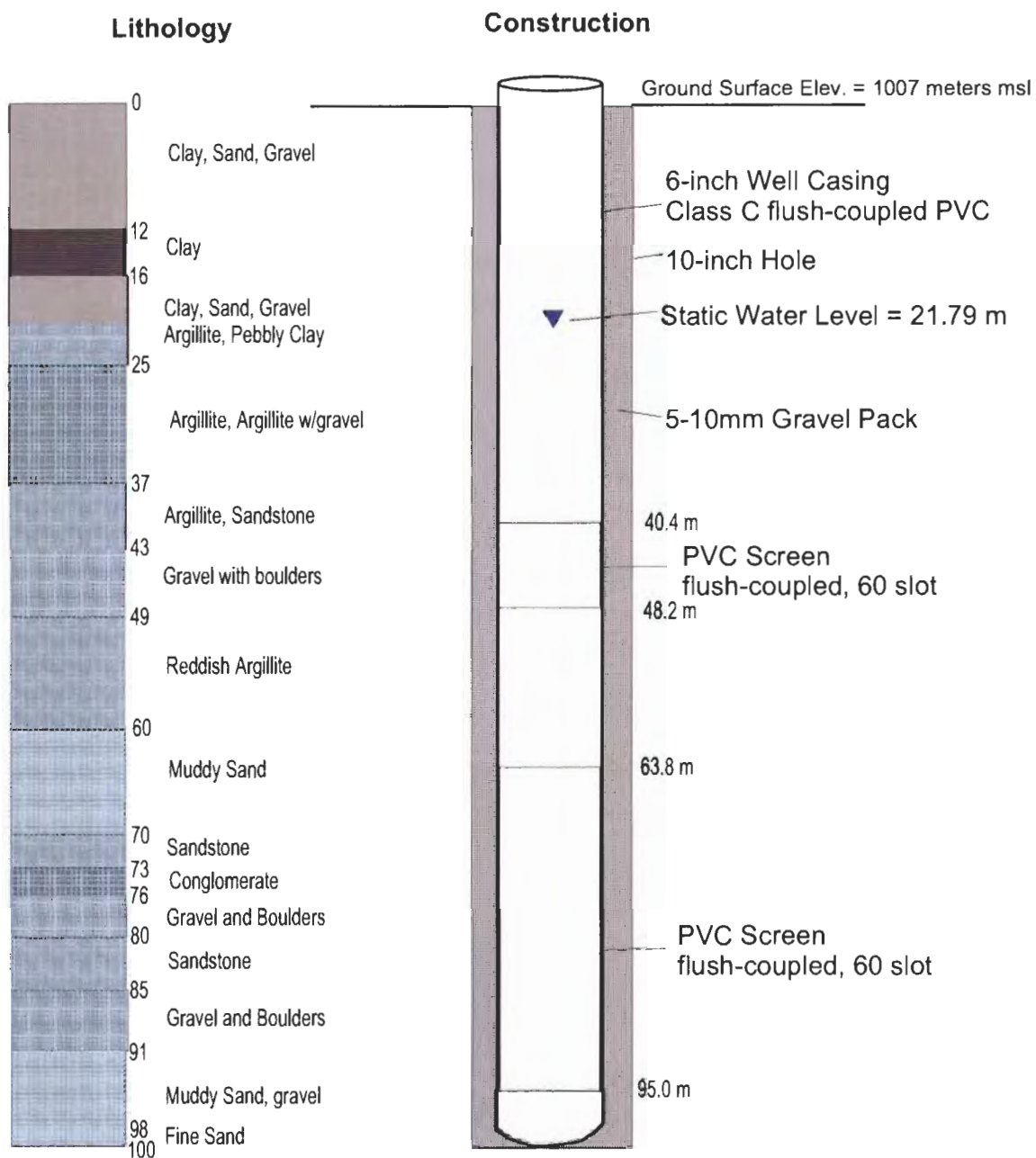
Estimated Ground Water Contours (m - msl)
March 2003

Figure 1.2



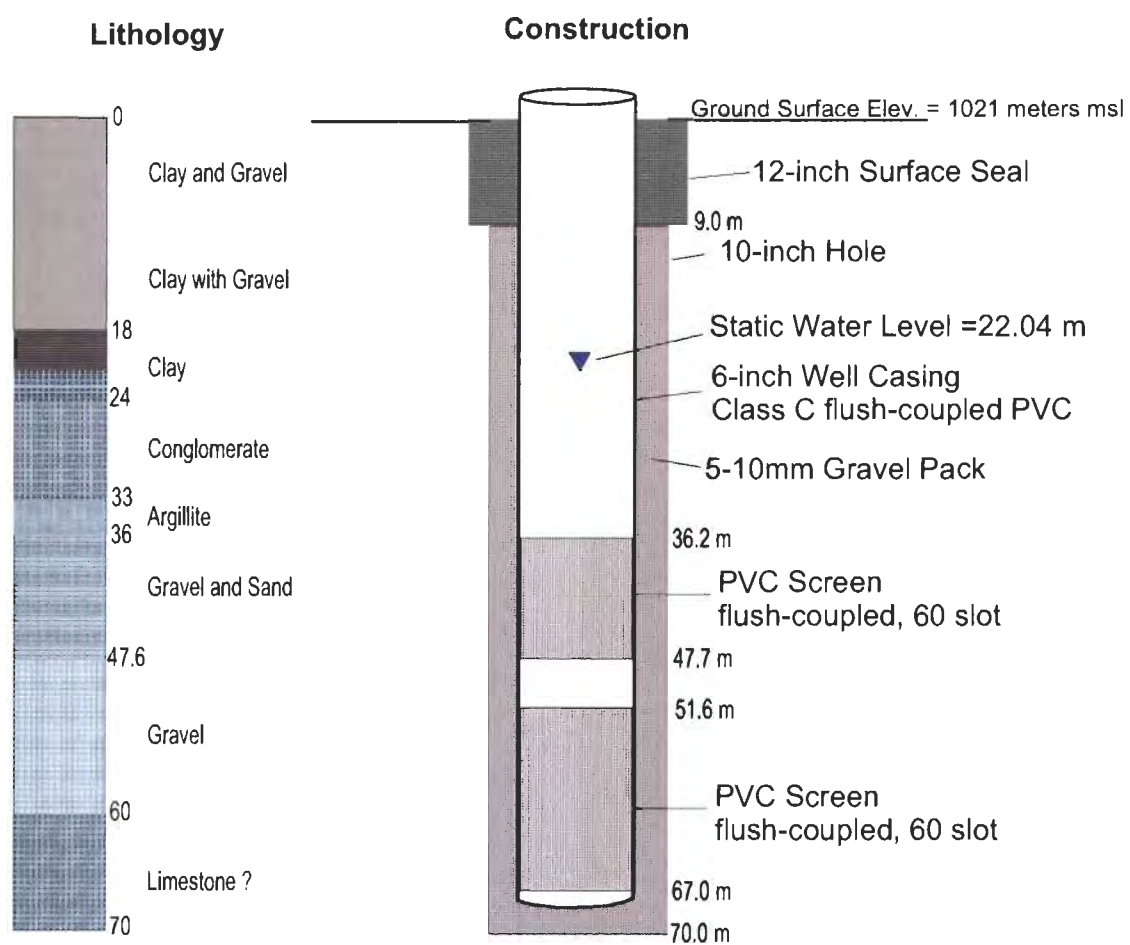
Kandahar Groundwater
CAWSS TW1

Figure 4.1



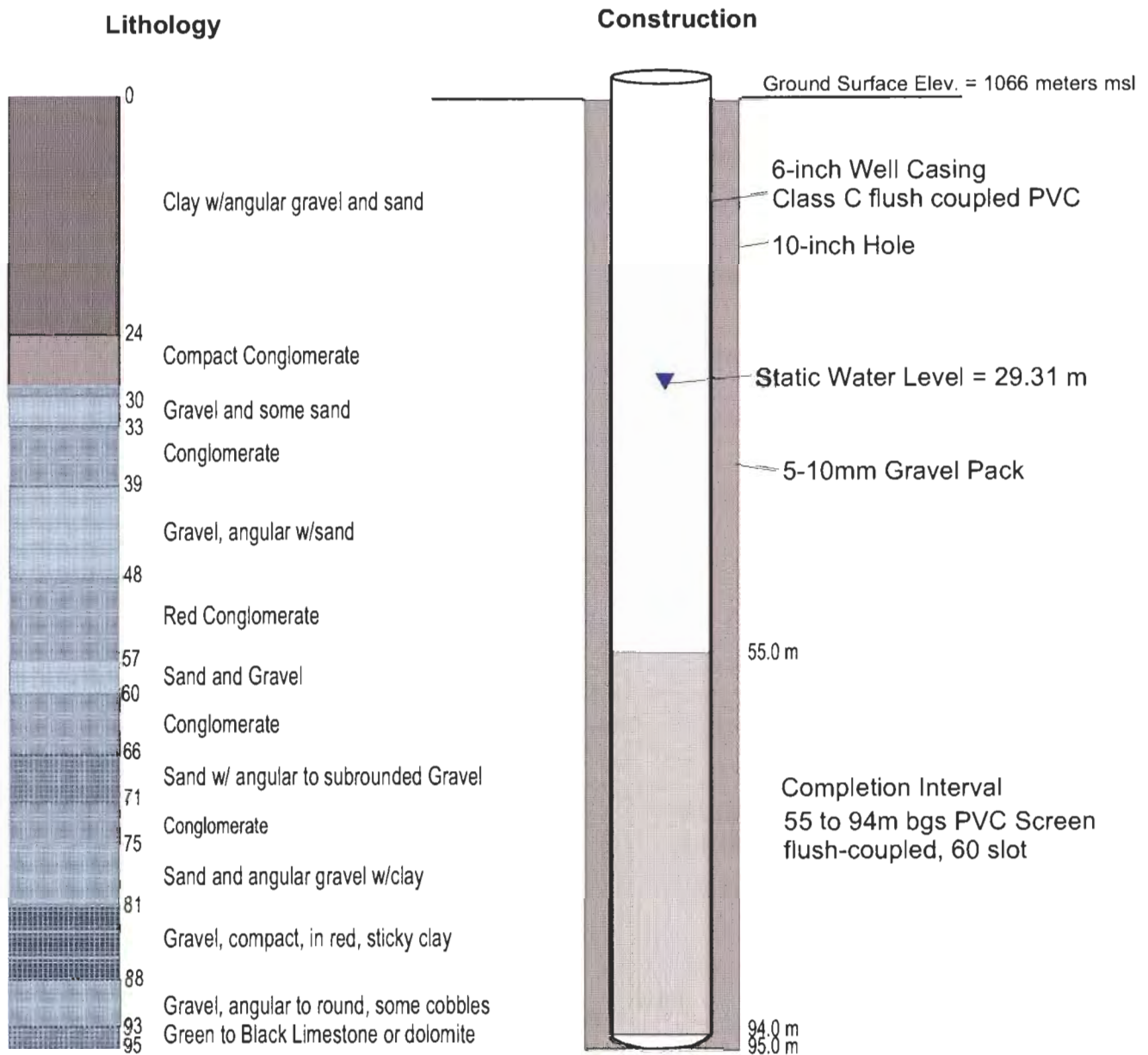
Kandahar Groundwater
CAWSS TW2

Figure 4.2



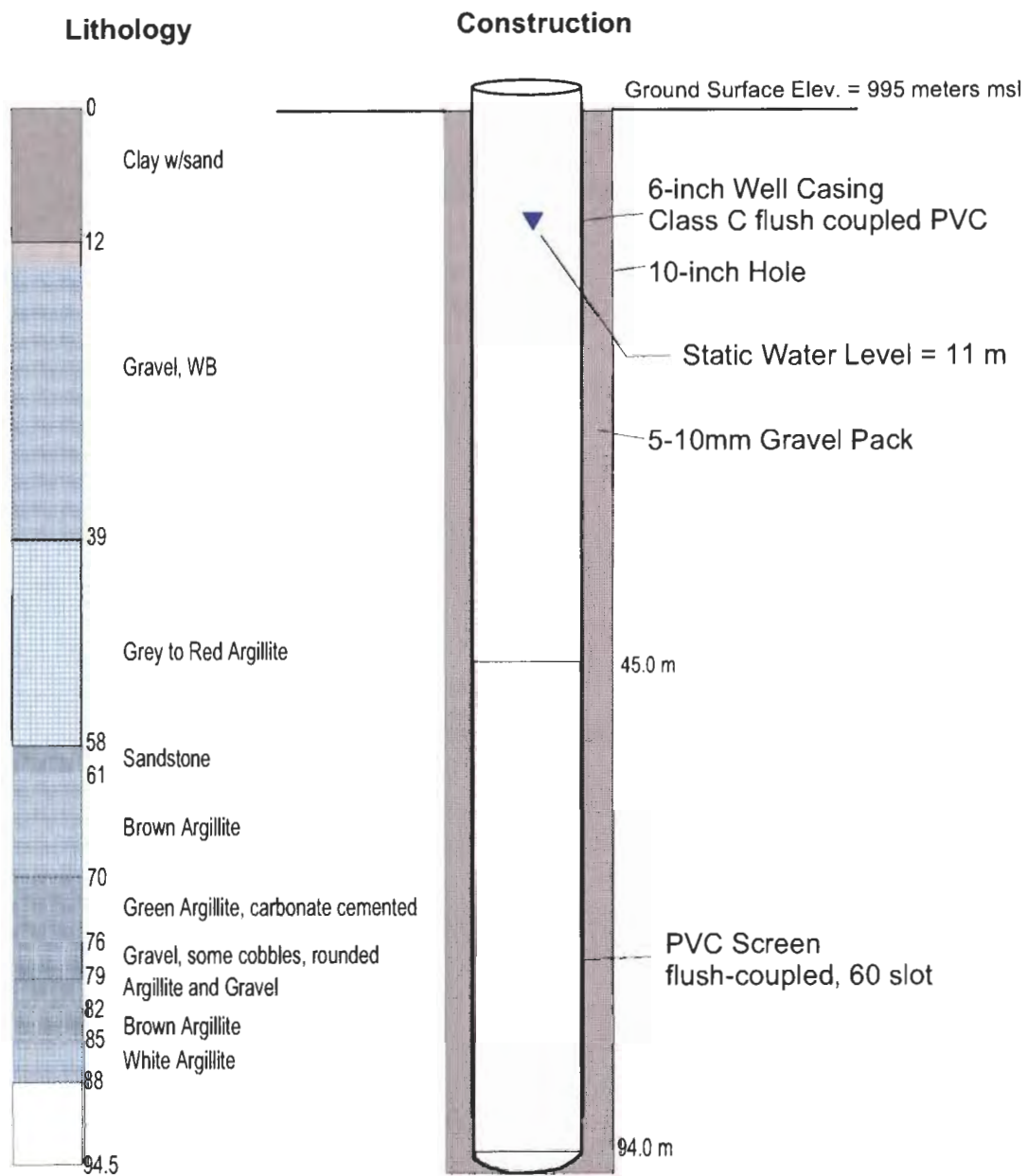
Kandahar Groundwater
Sadat Ghundai TW3

Figure 4.3



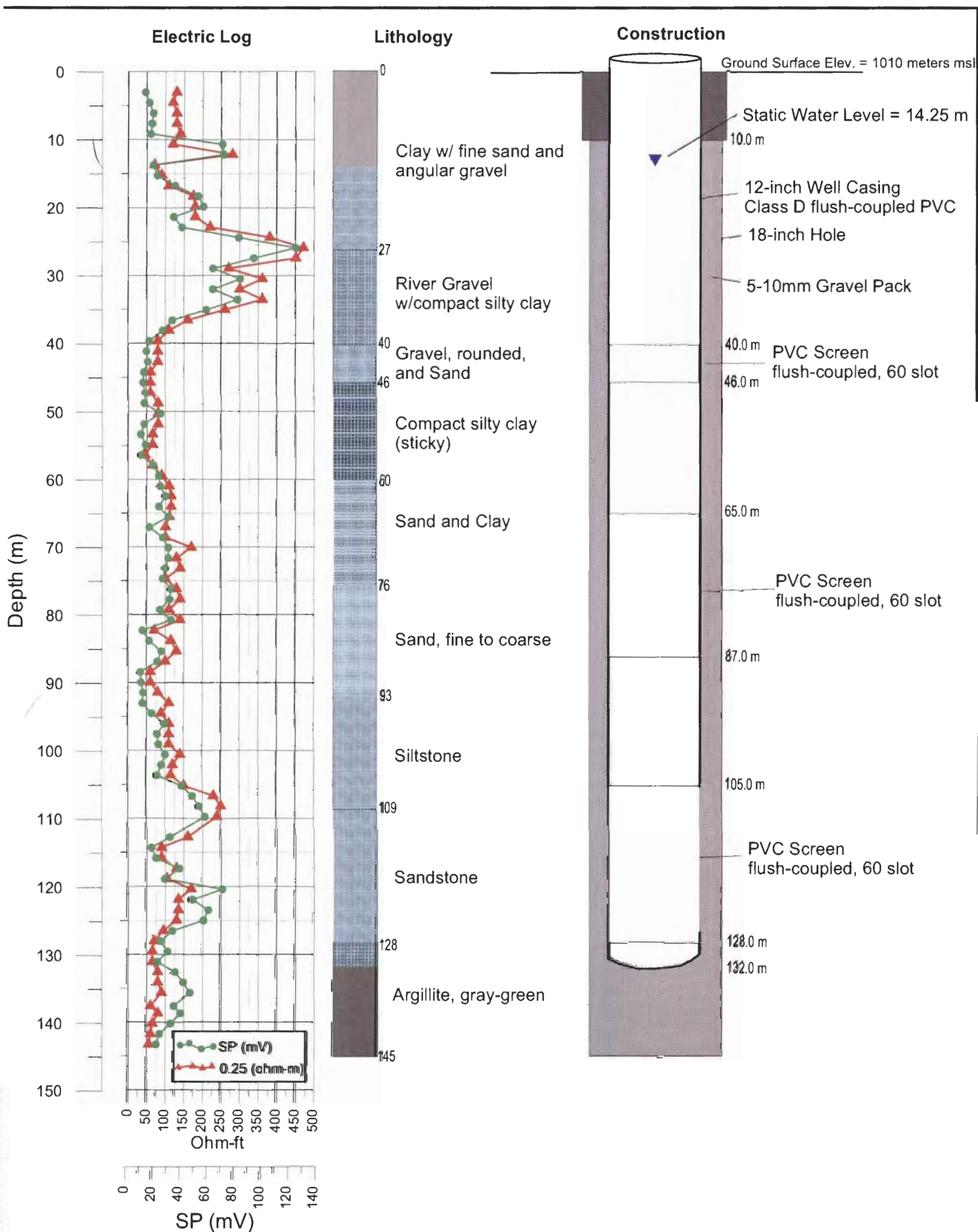
Kandahar Groundwater
Lowi Walla TW4

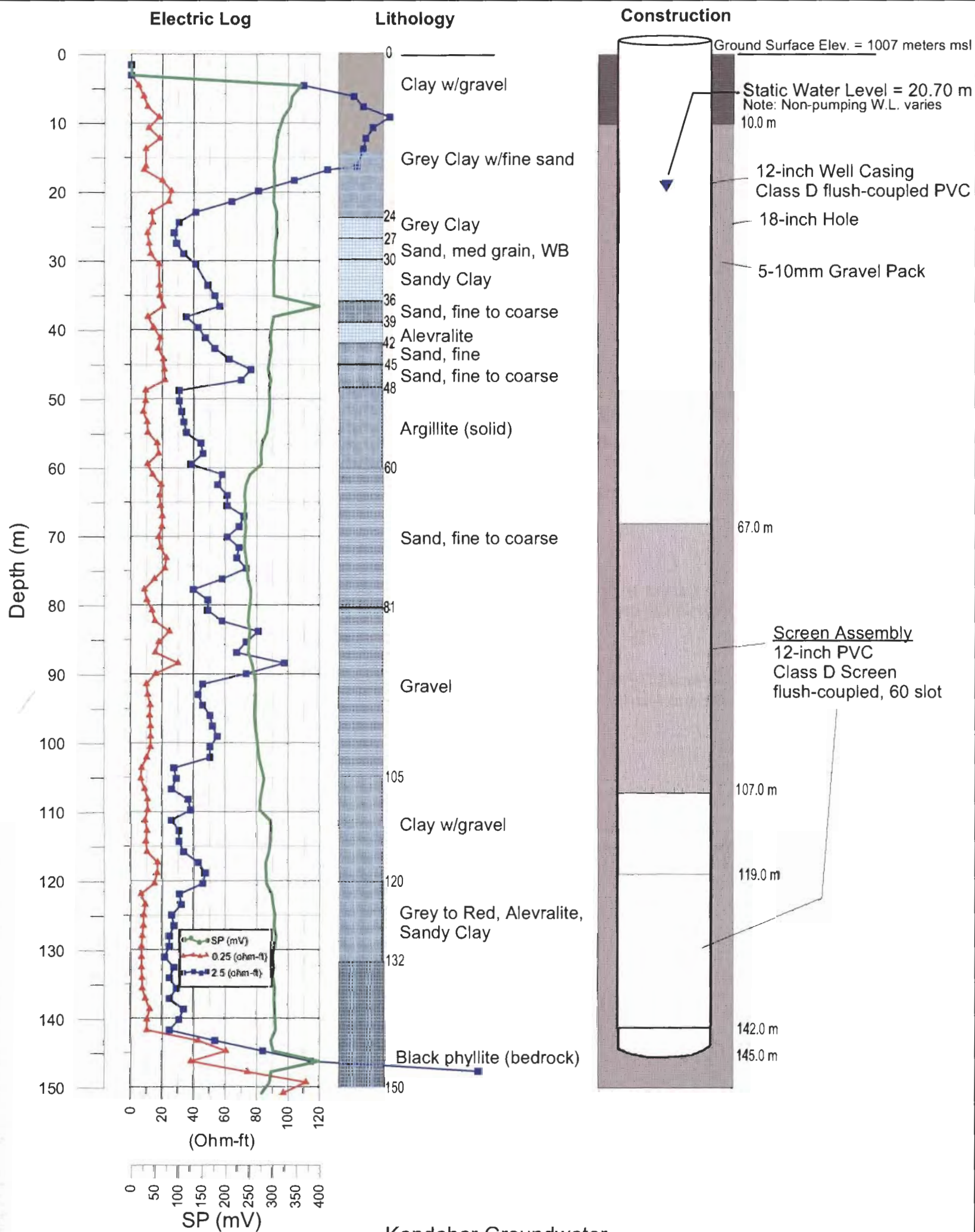
Figure 4.4



Kandahar Groundwater
HJ Karz Lycee TW5

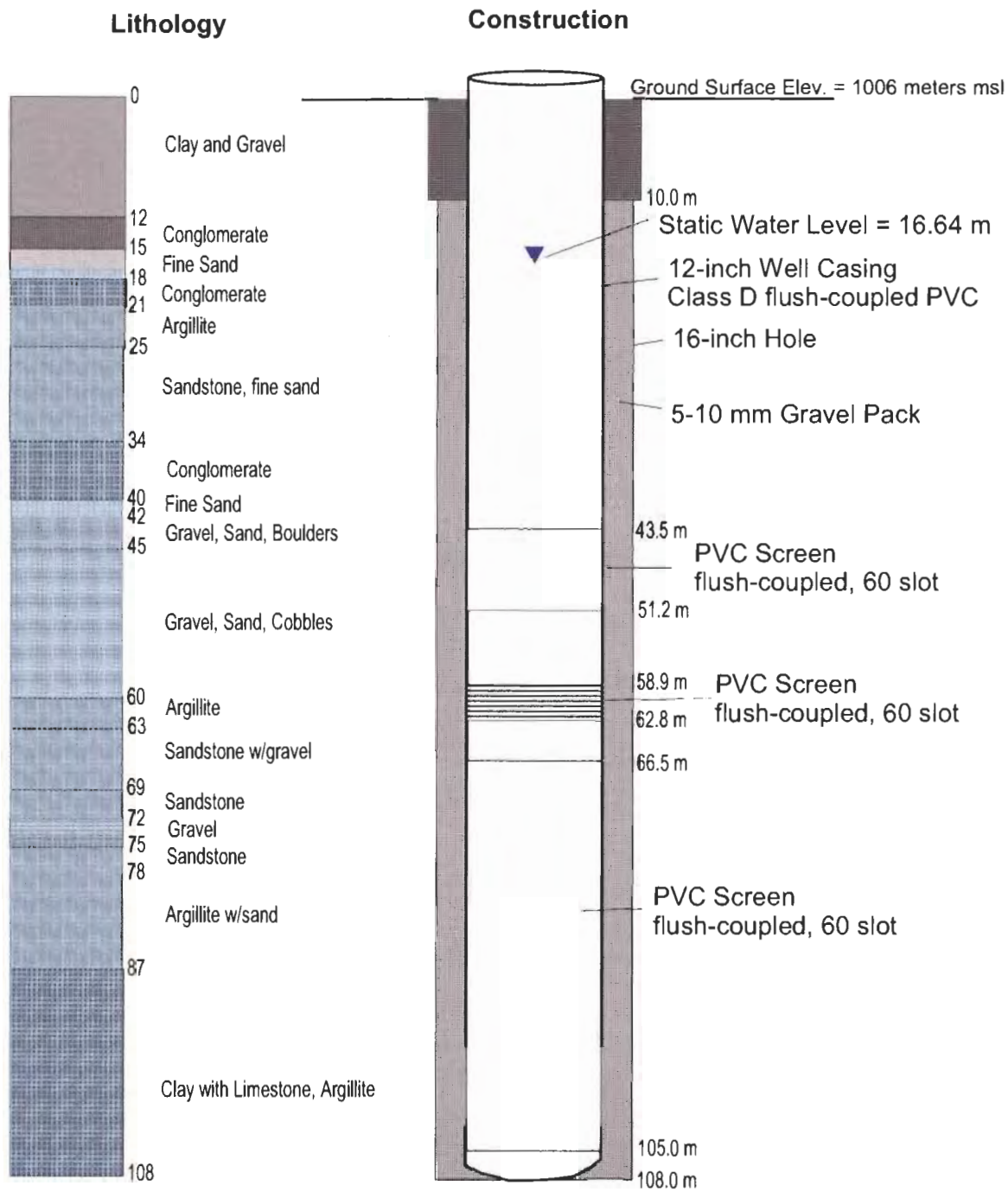
Figure 4.5





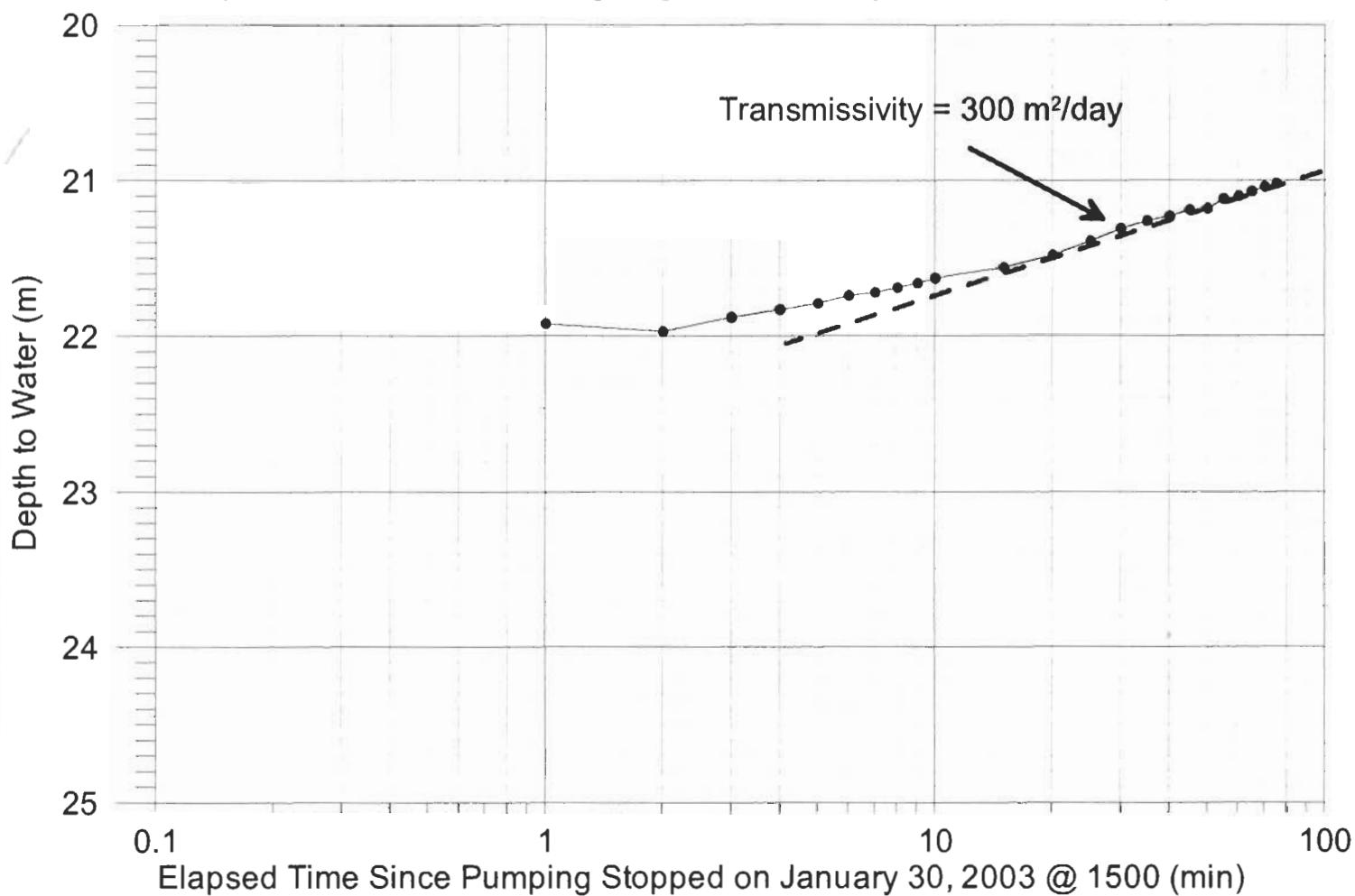
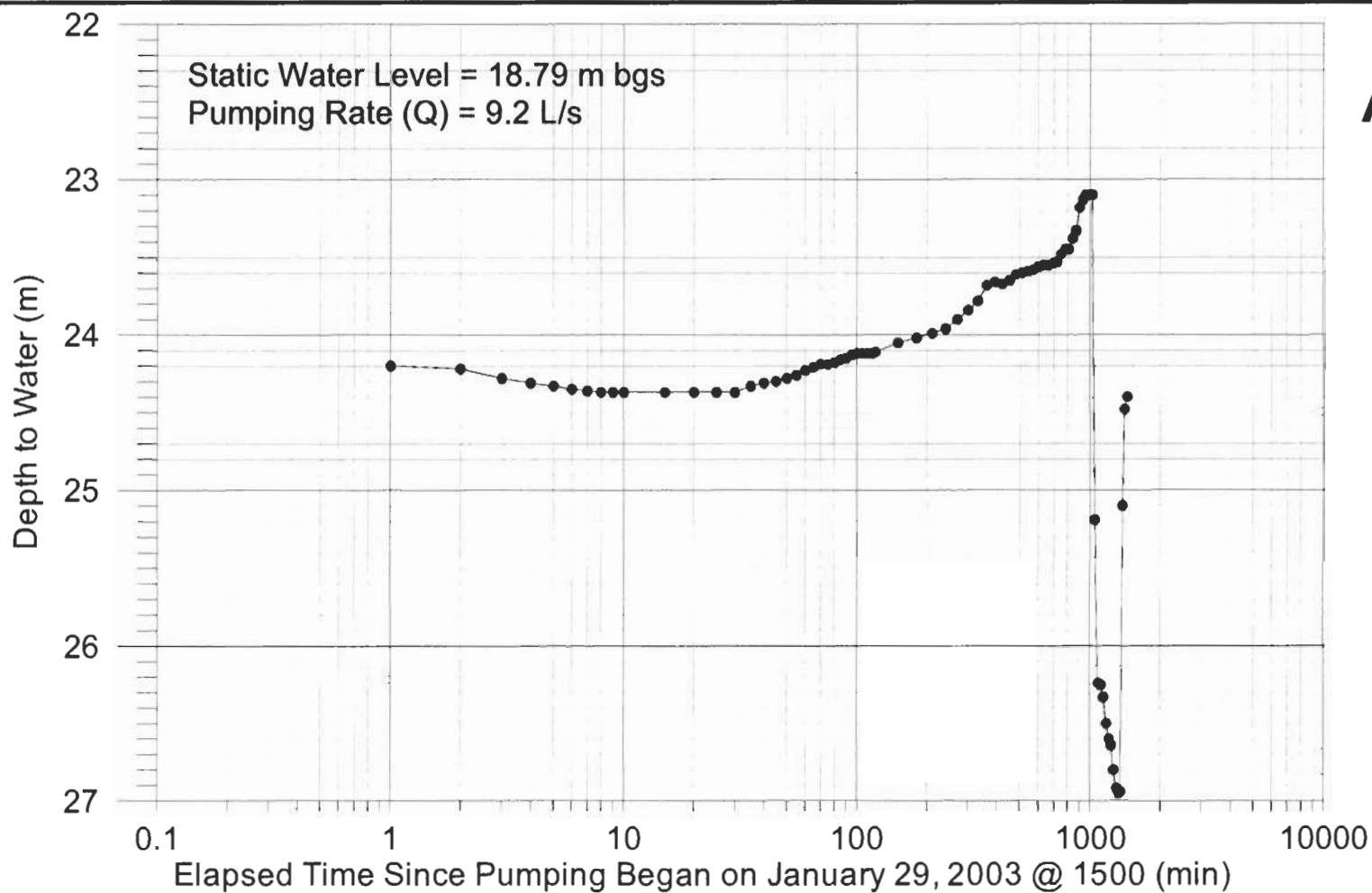
Kandahar Groundwater
Ahmad Shah Baba Lycee PW11

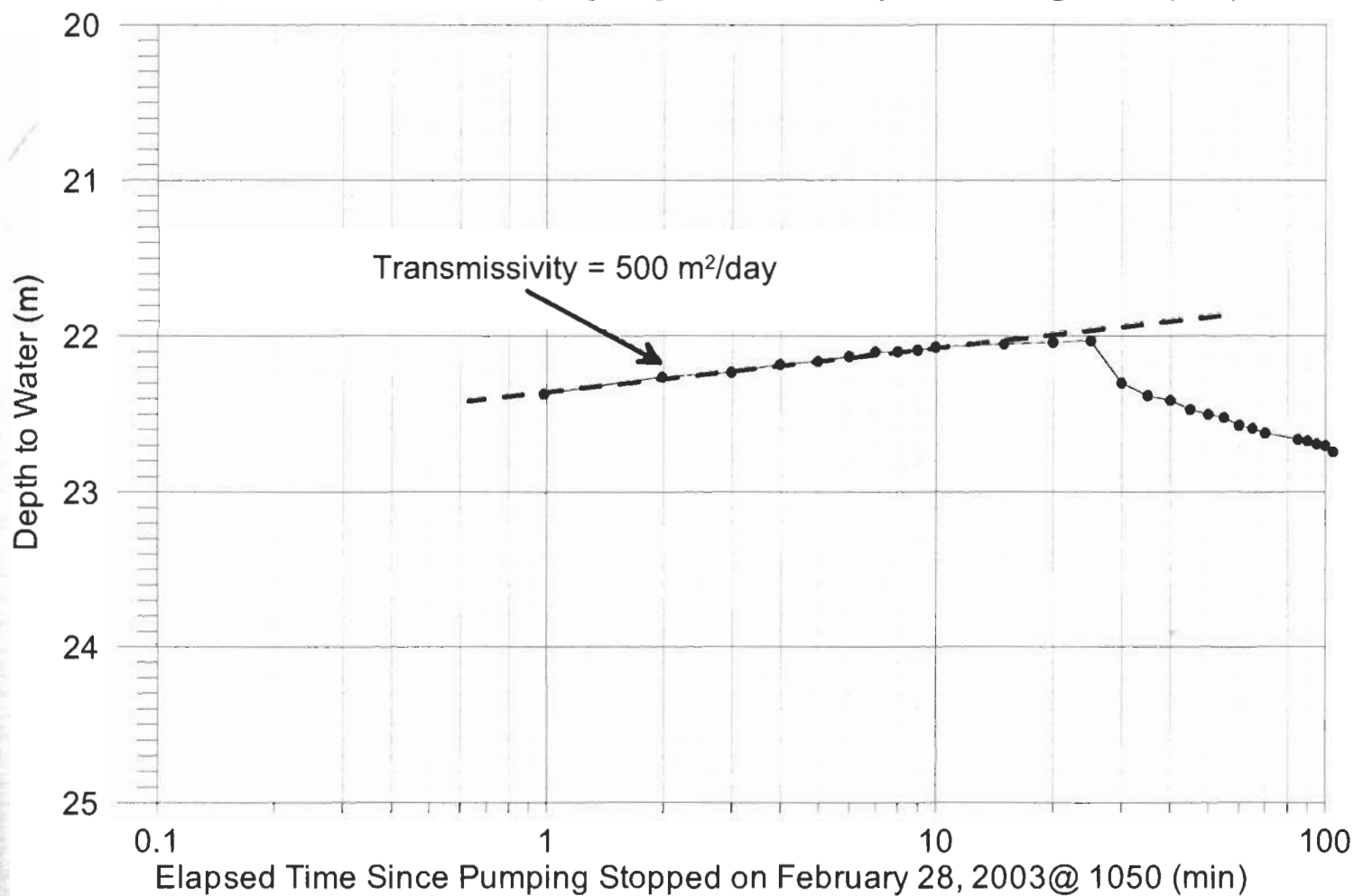
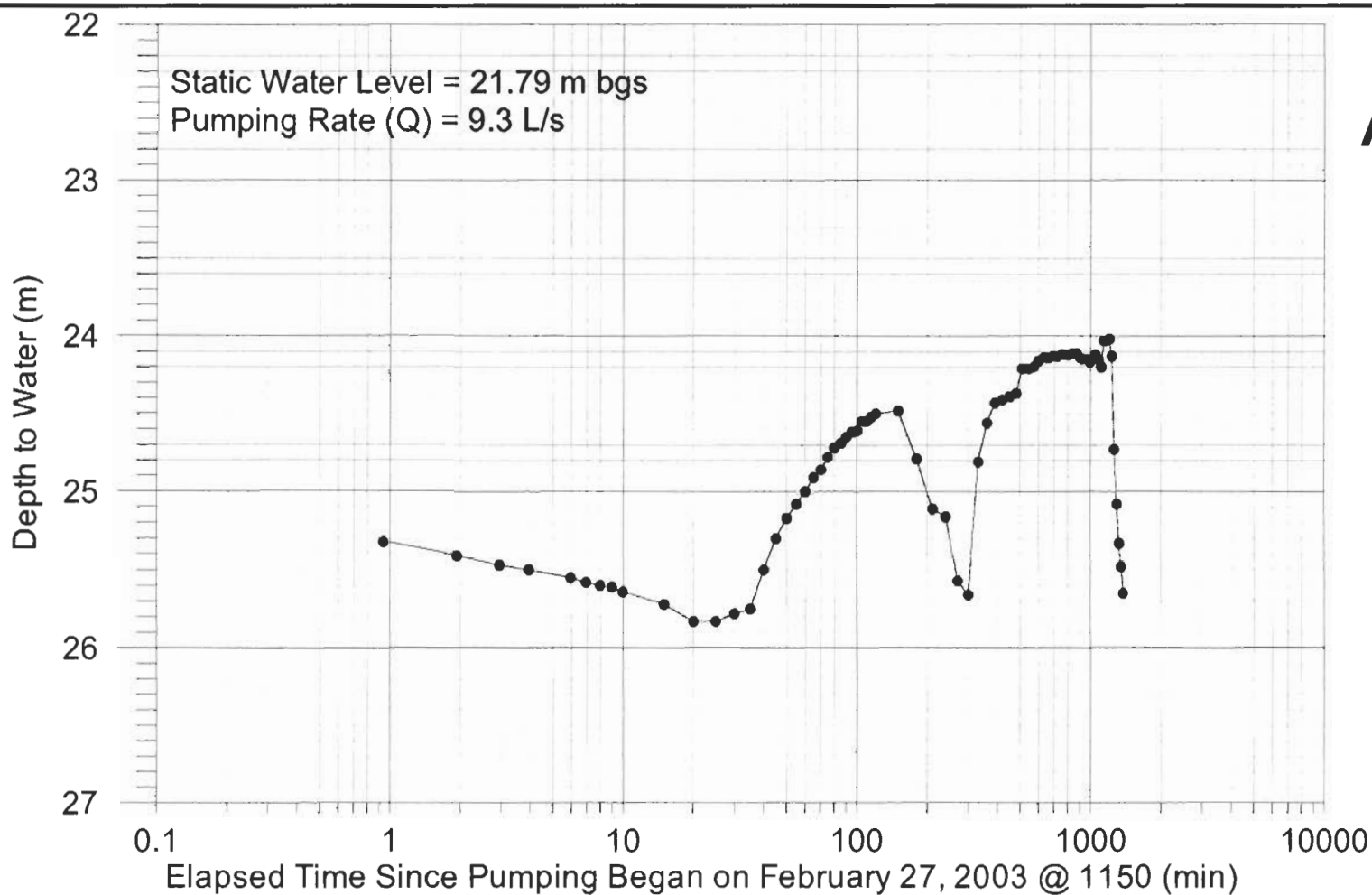
Figure 4.7



Kandahar Groundwater
Mah Bas Prison PW13

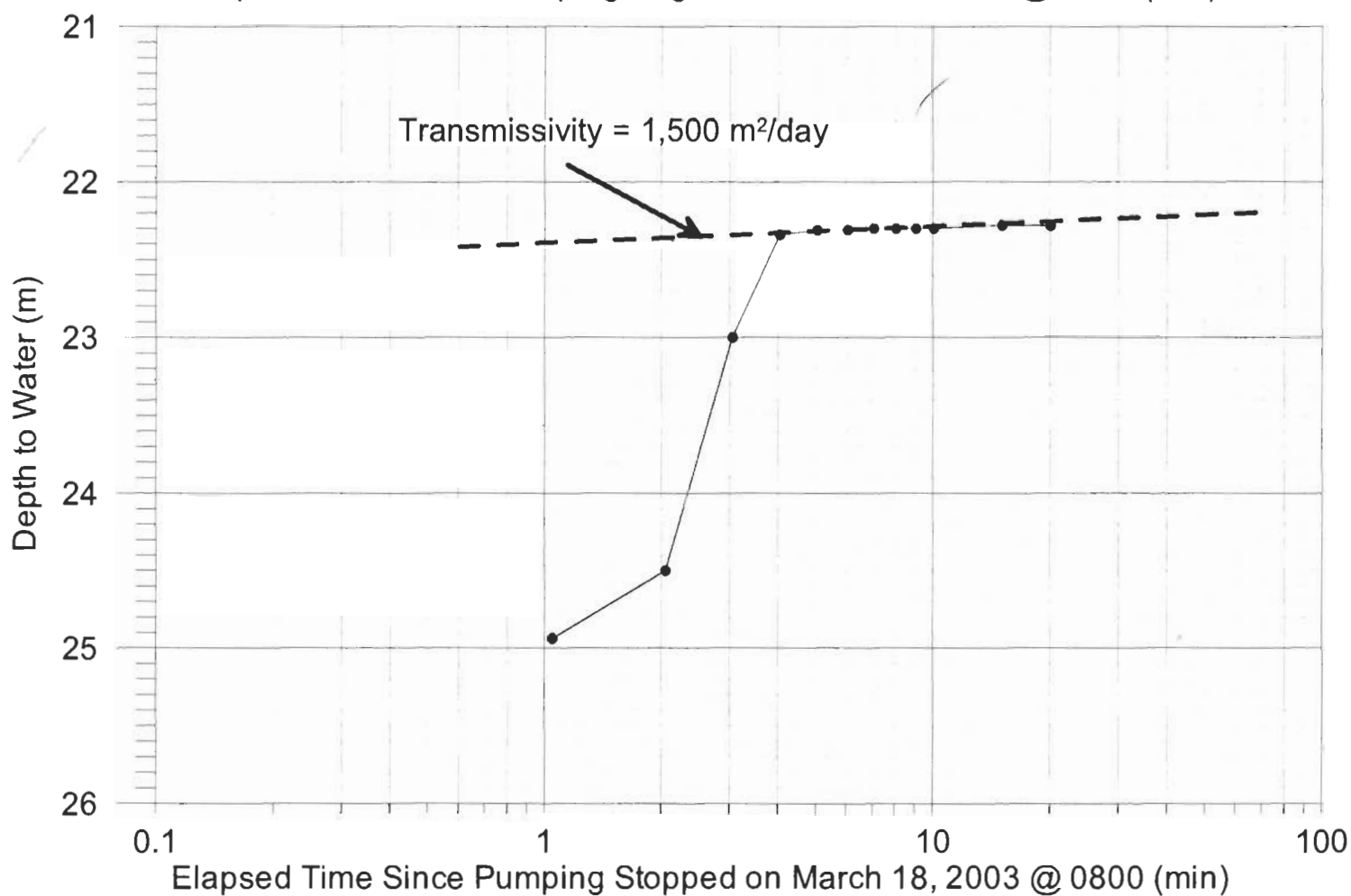
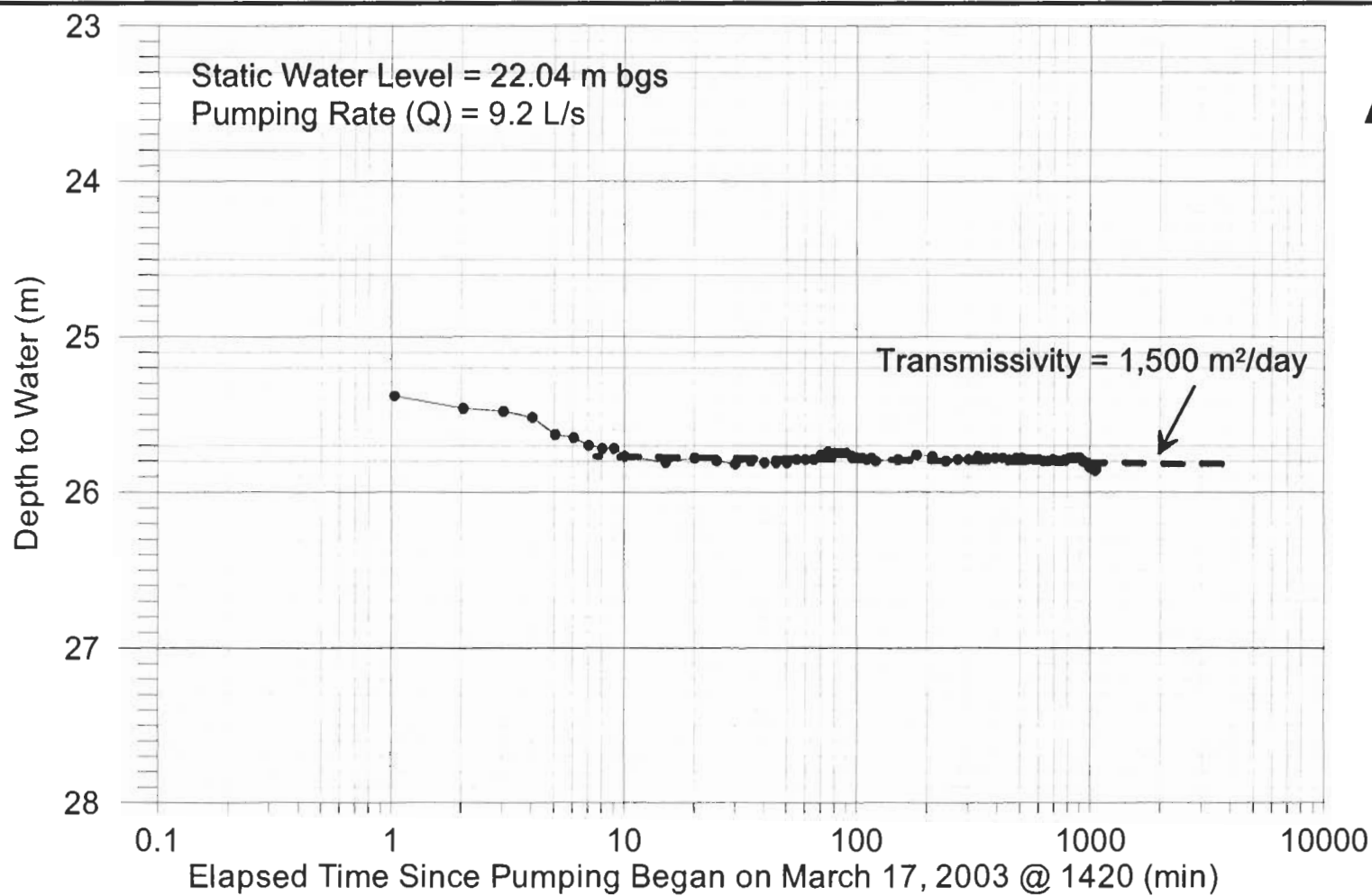
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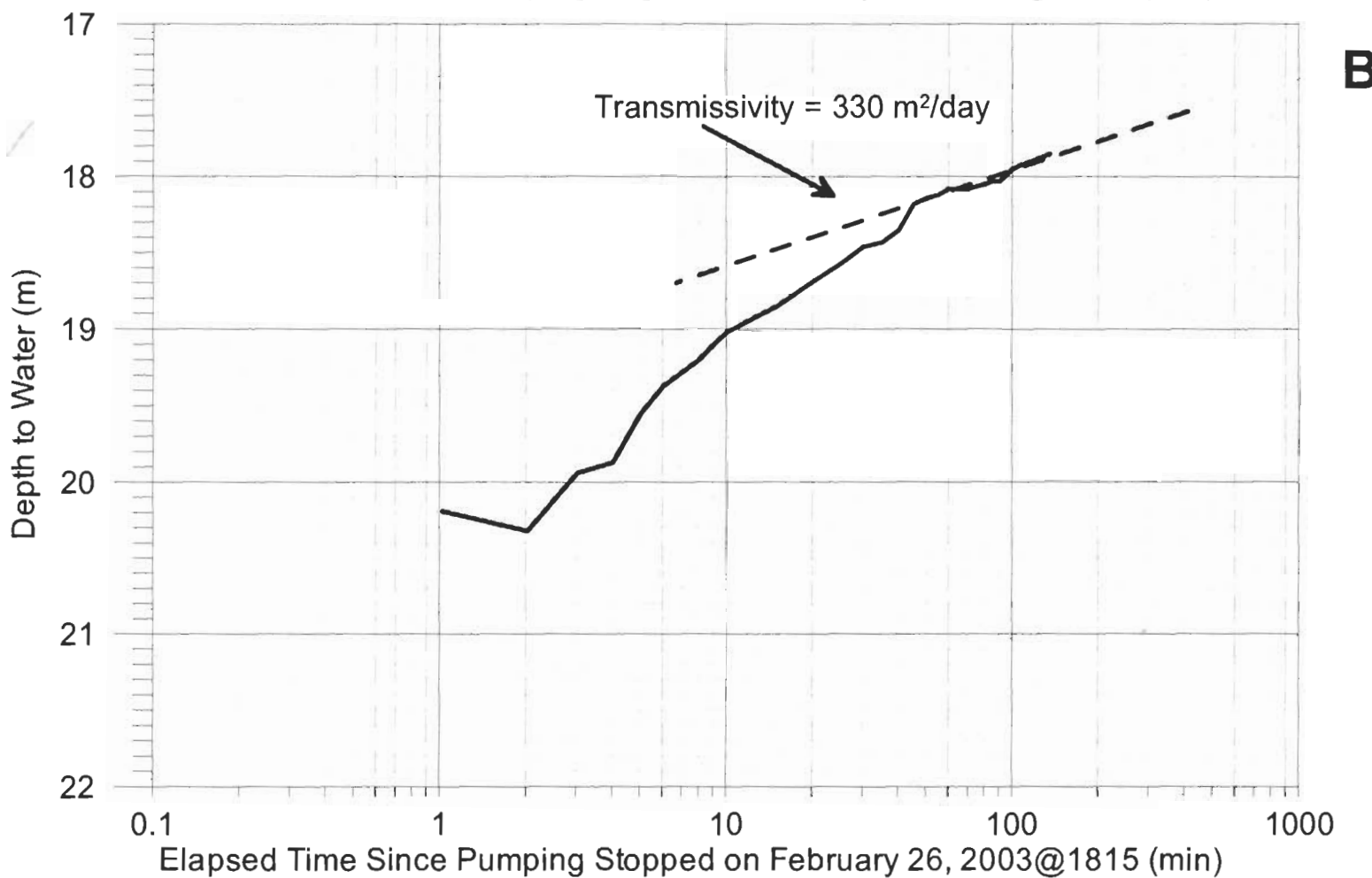
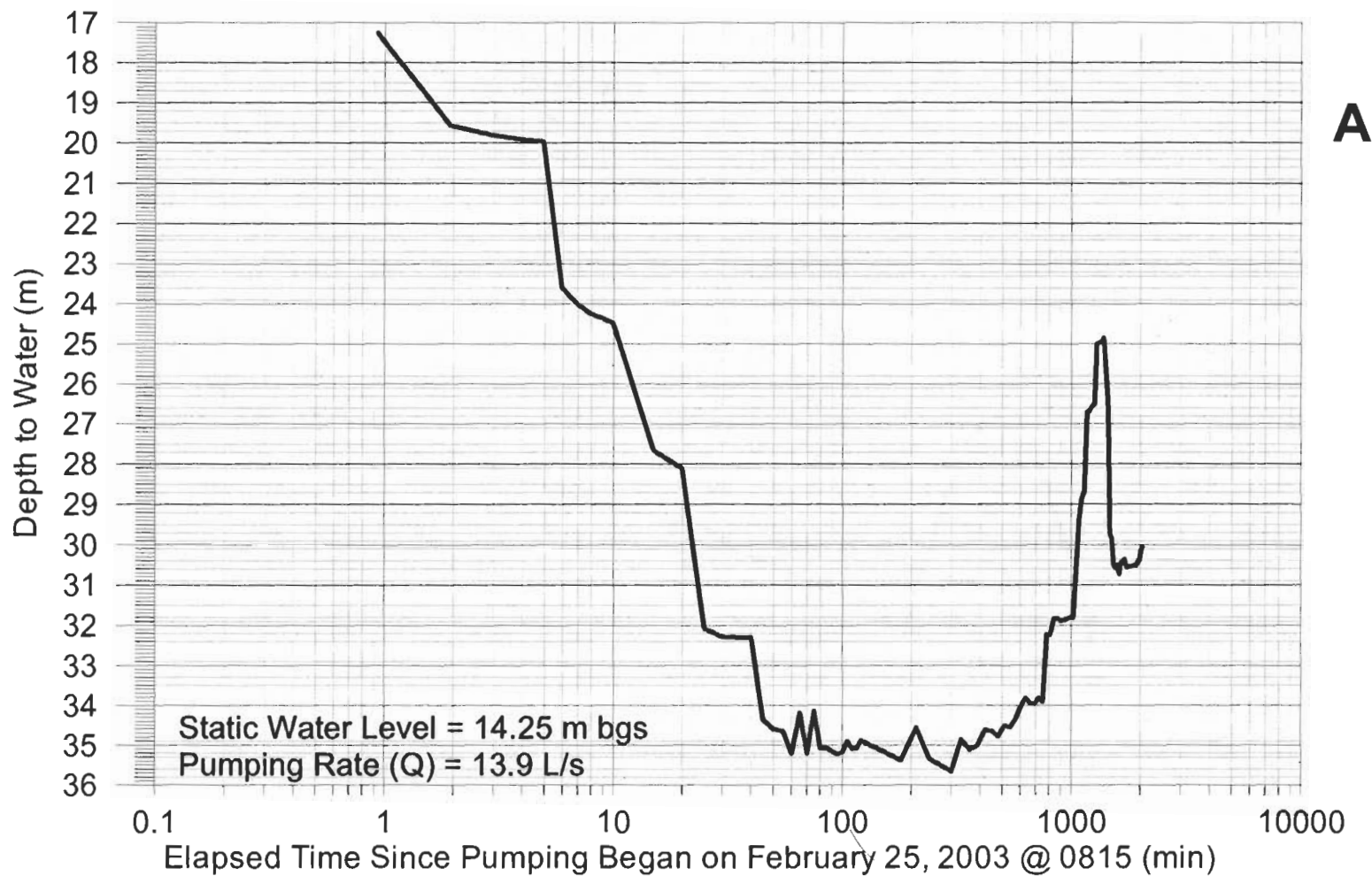




CAWSS TW2 Time Drawdown / Time Recovery
24-hour Pumping Test

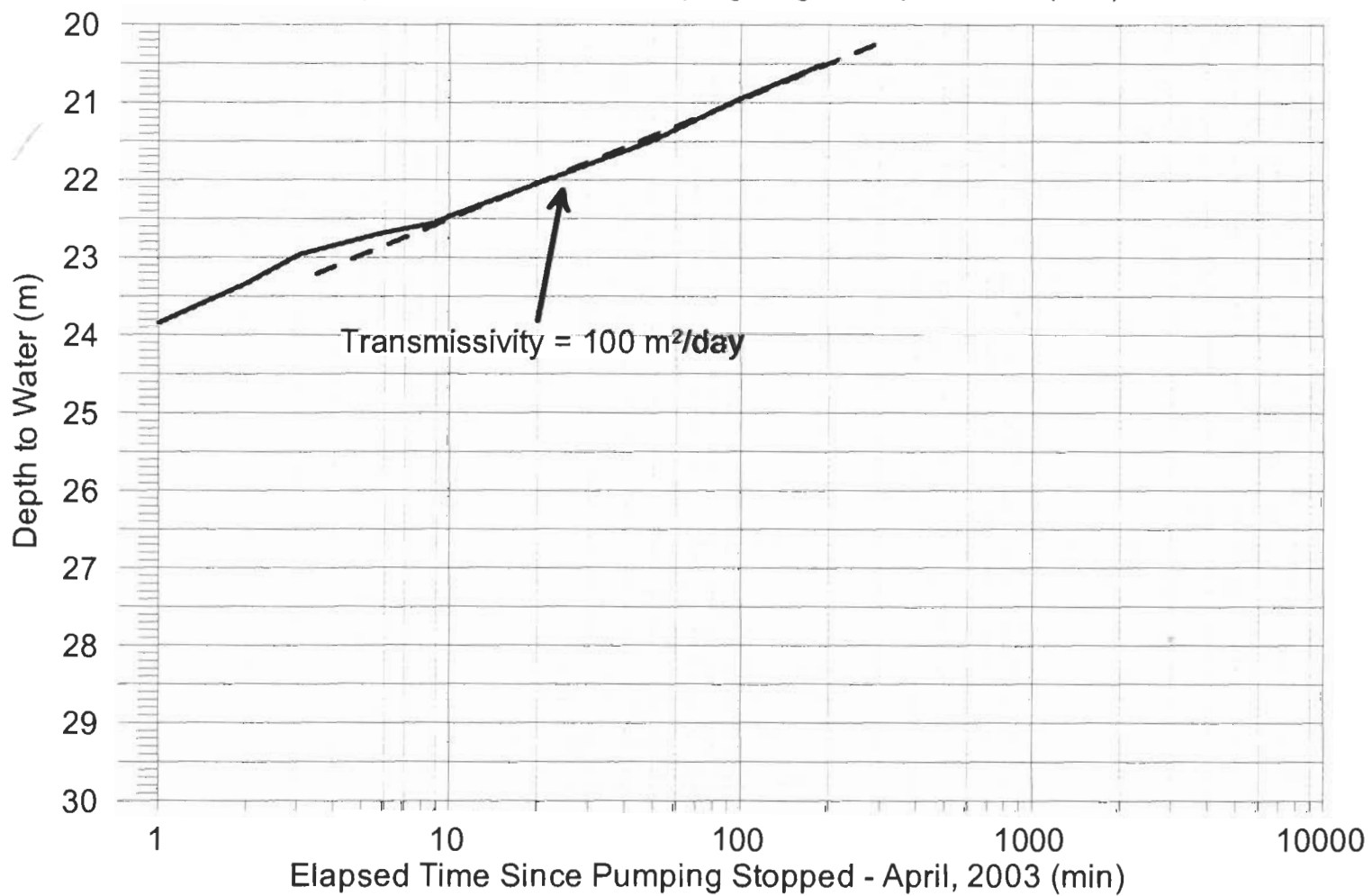
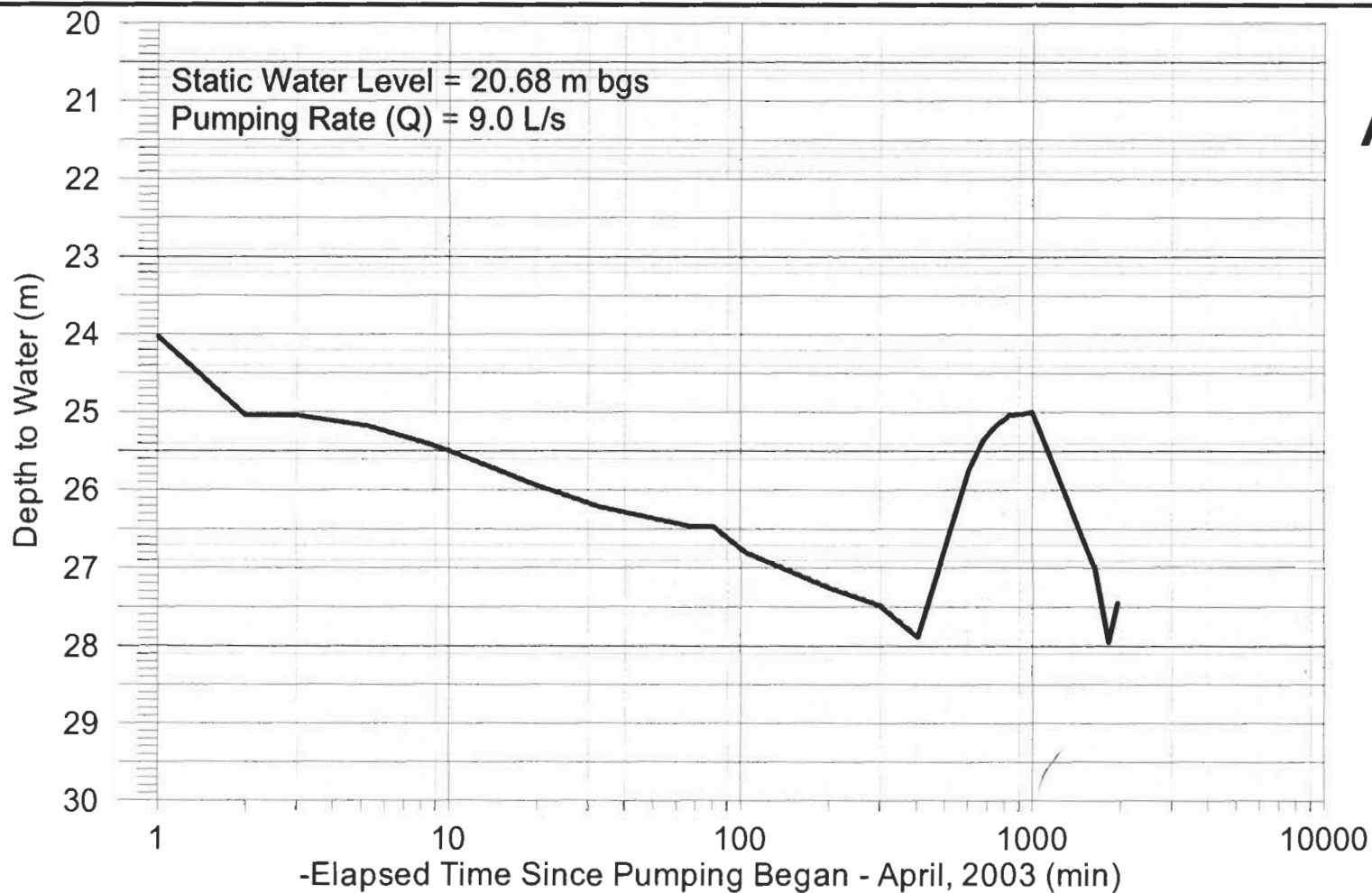
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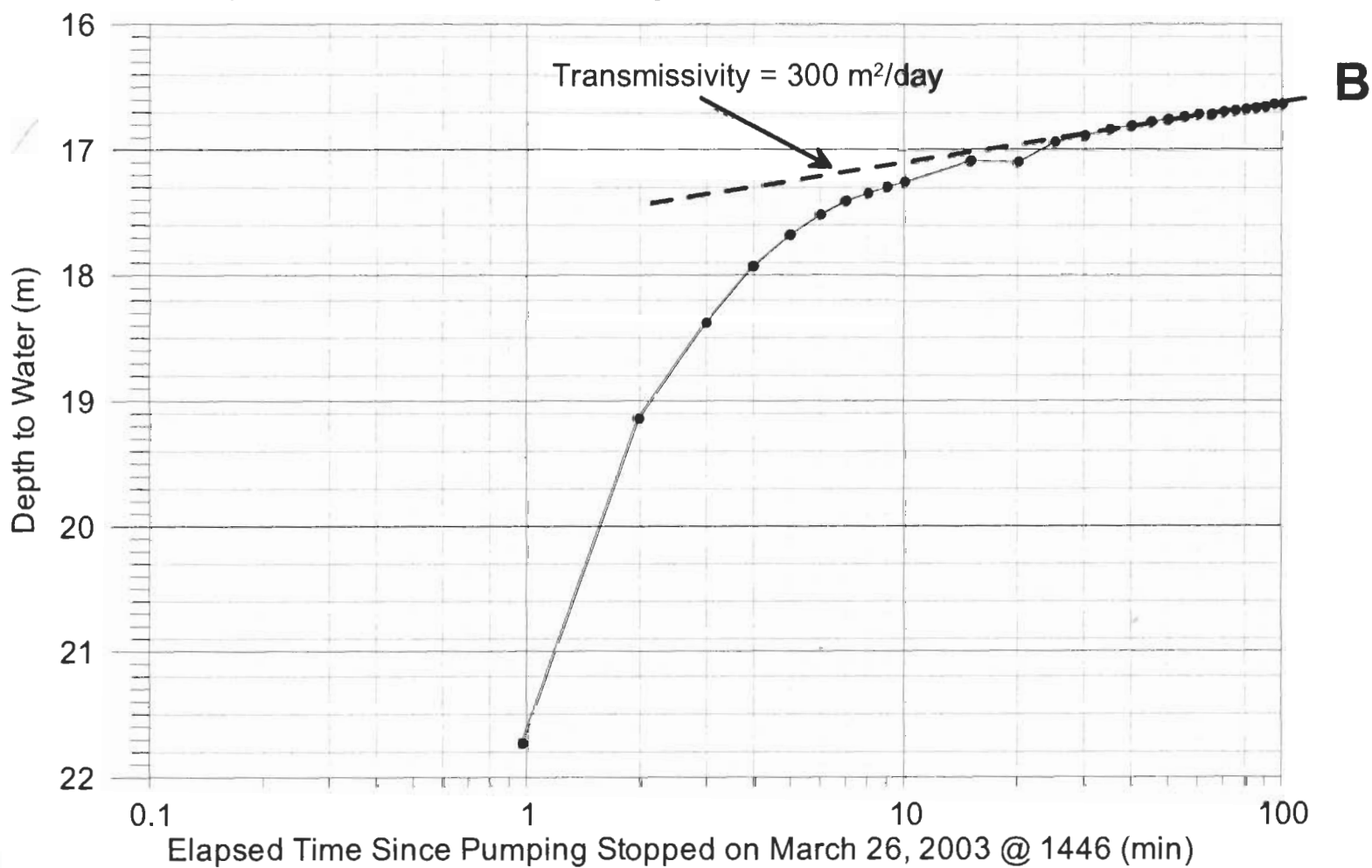
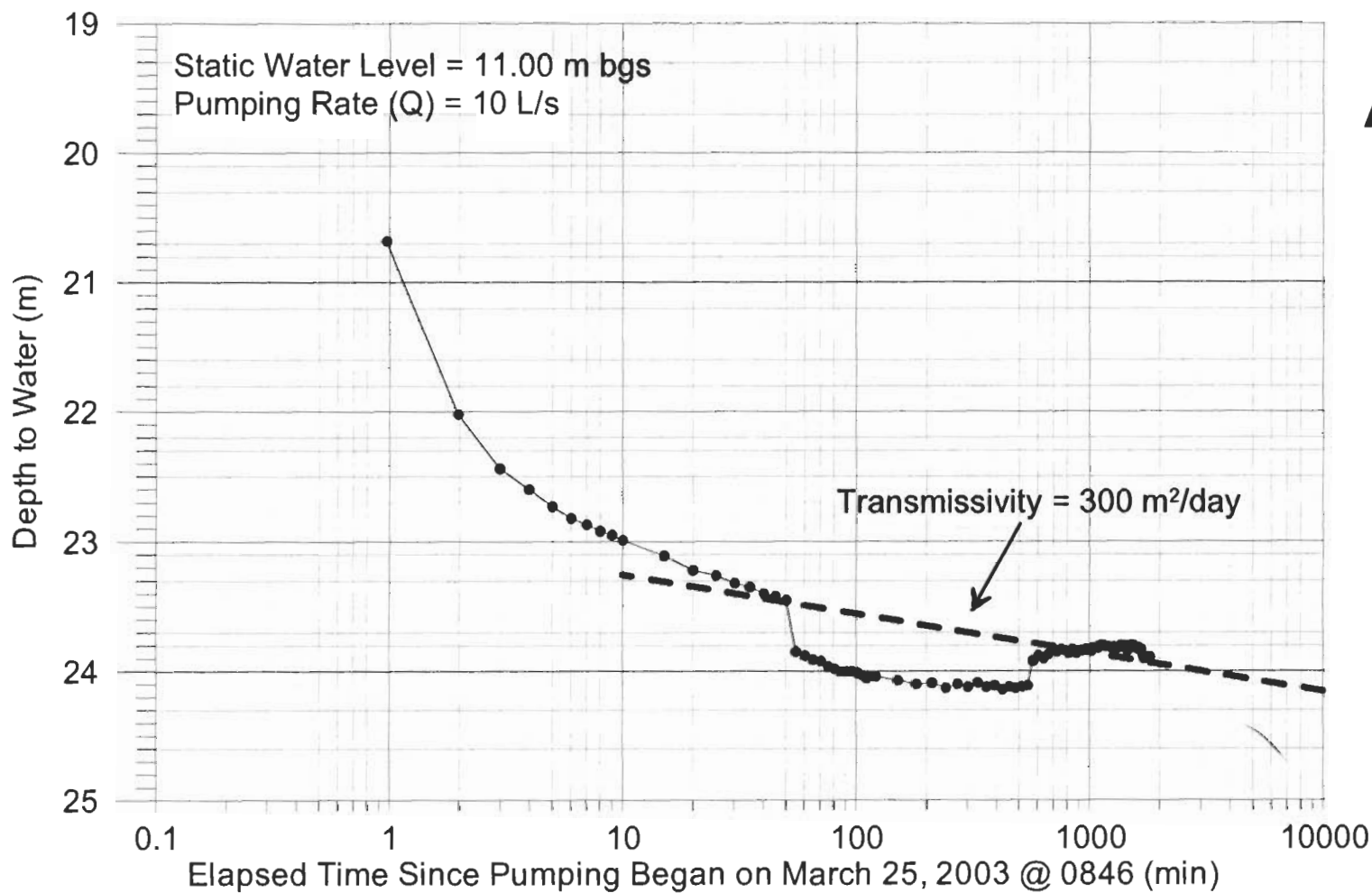
Mir Wais Lycee PW12 Time Drawdown / Time Recovery
Pumping Test

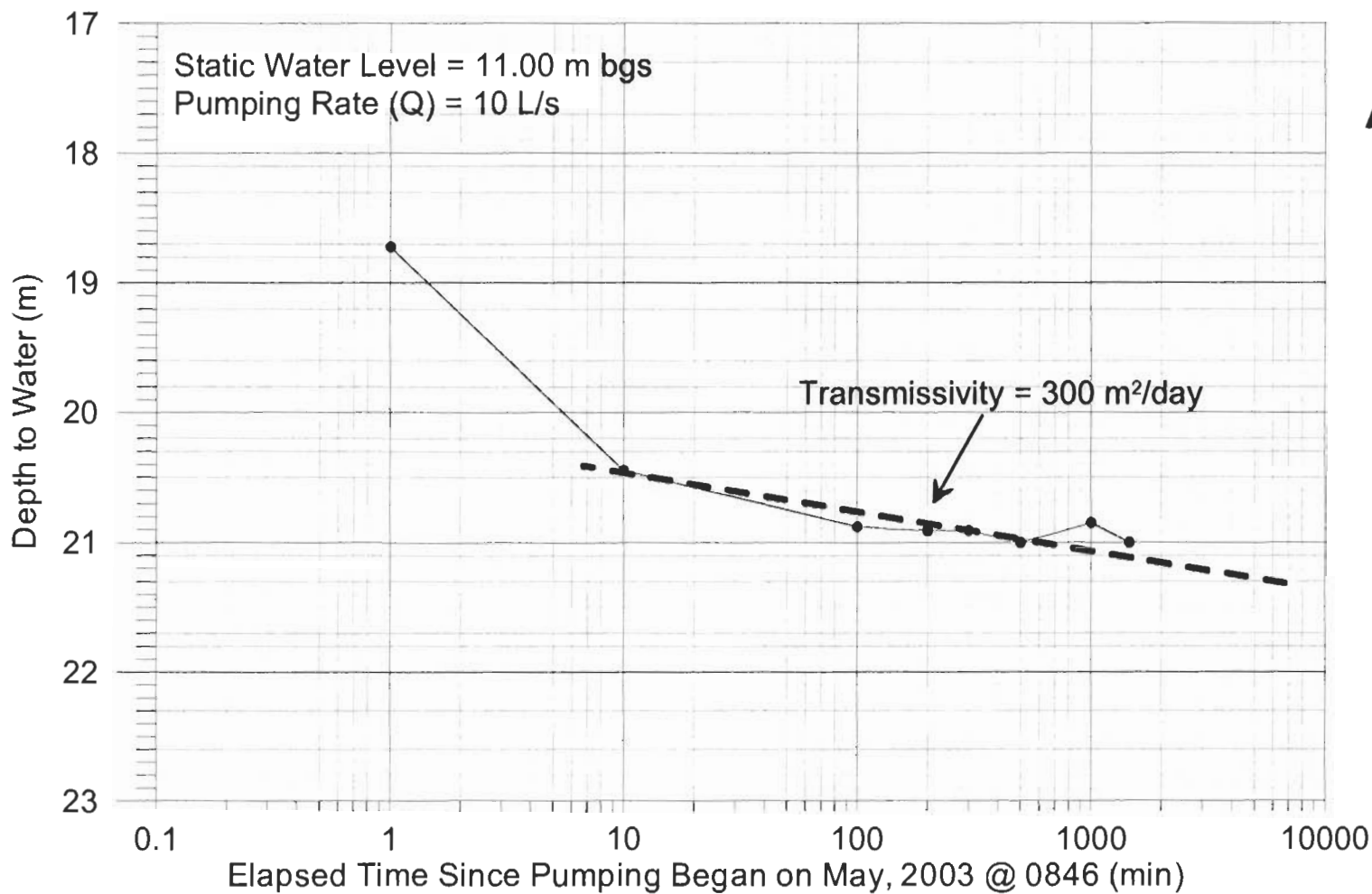
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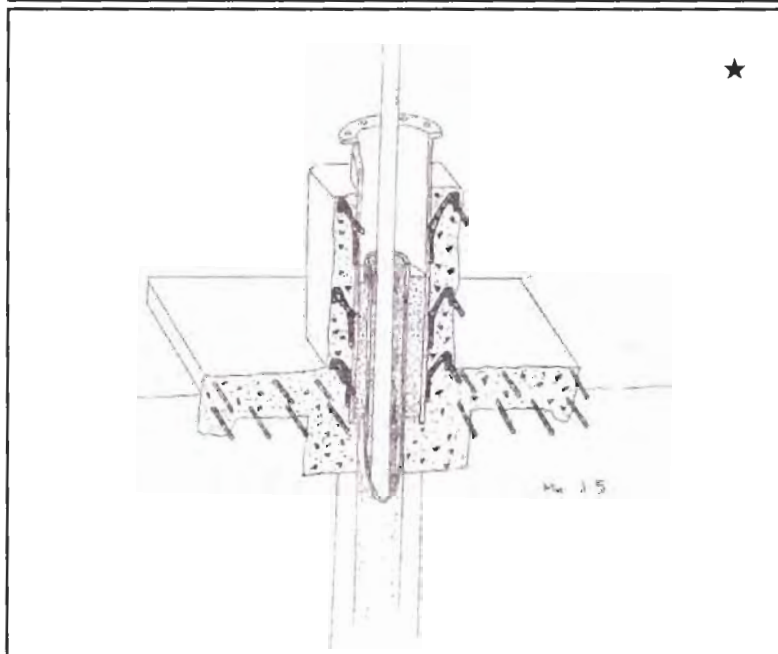
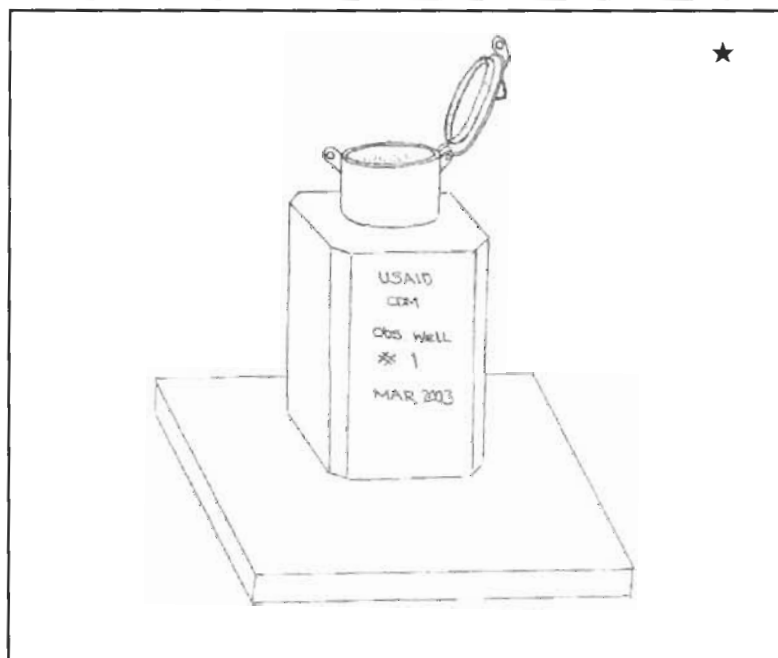
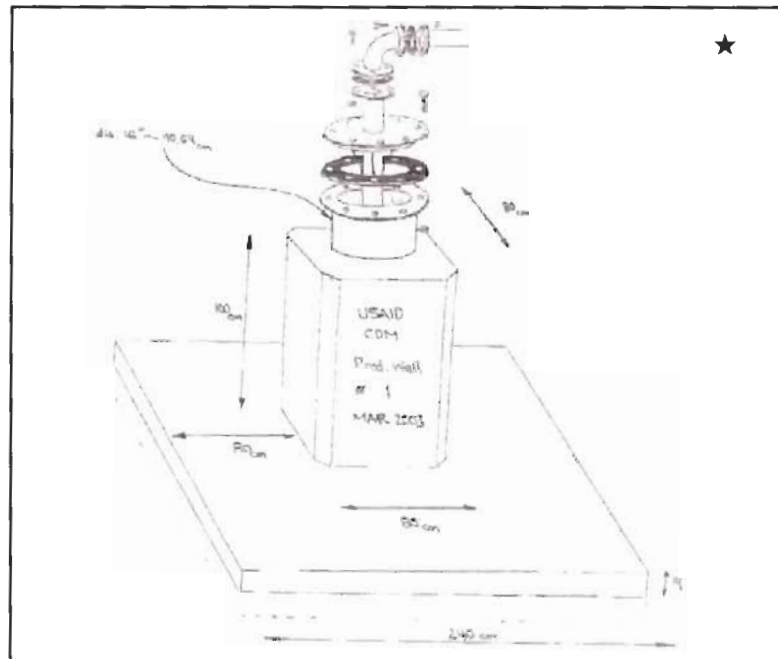


Ahmad Shah Baba Lycee PW11 Time Drawdown / Time Recovery
24-hour Pumping Test

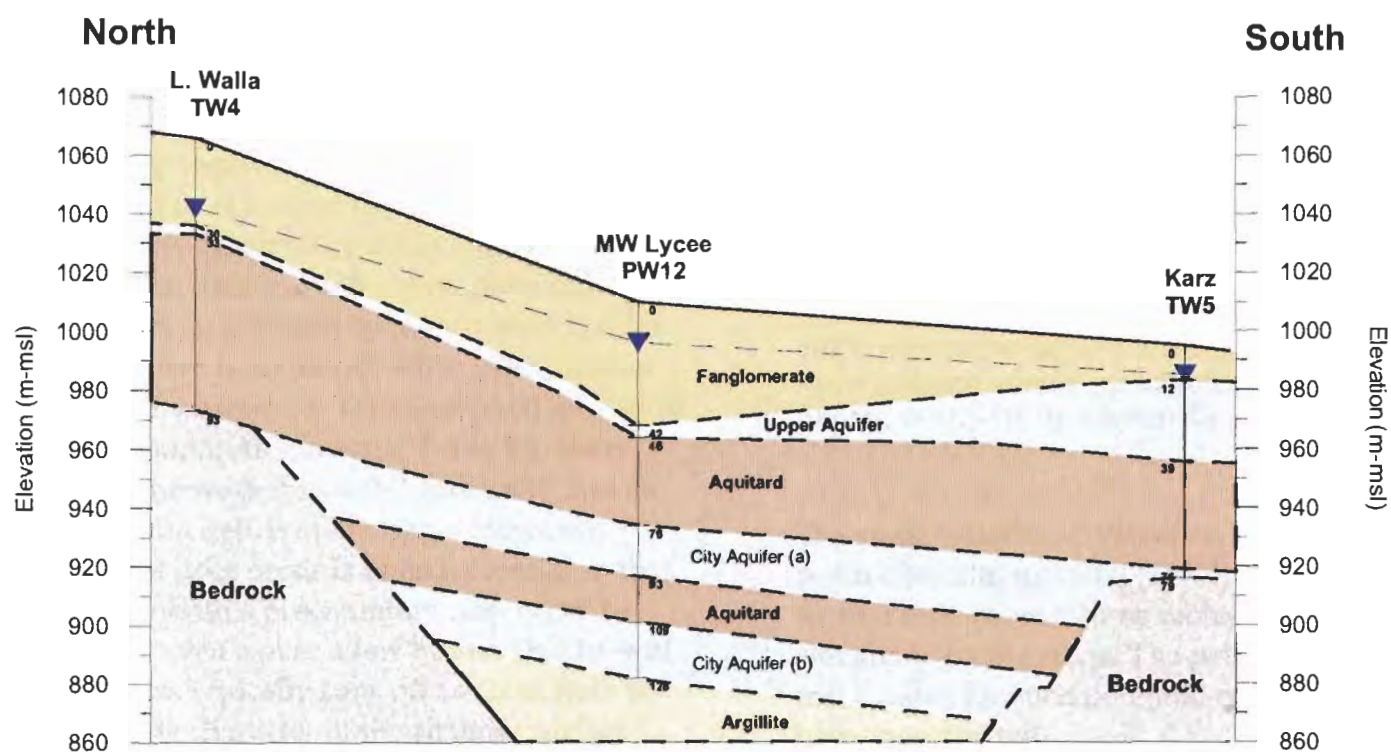
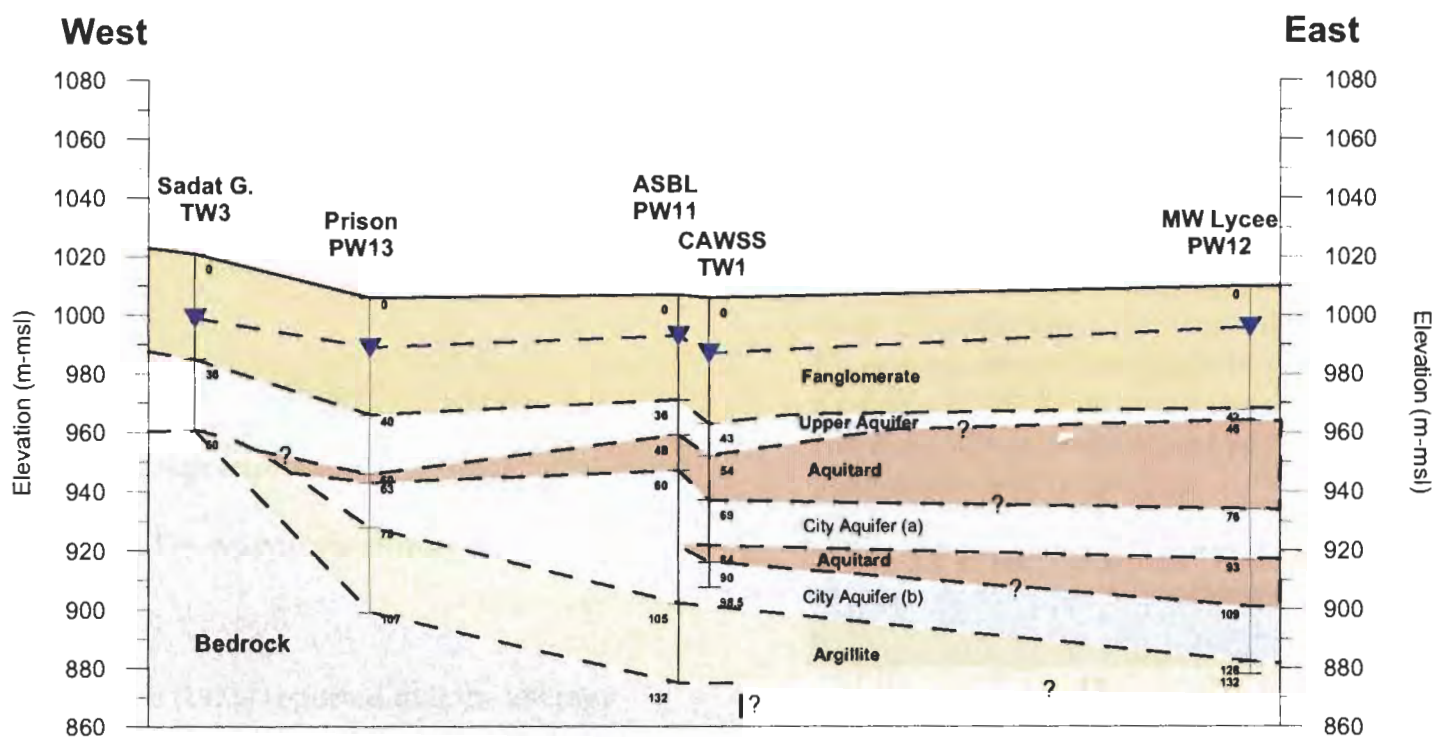
Figure 4.13







★ Prepared by Eng. Hamidullah Bahlo



Fanglomerate
Aquifer
Aquitard

Argillite
Bedrock

Scale (m)
0 1000 2000 4000

Static Water Level
Lithologic Contact
Depth below ground surface (m)

Kandahar City, Afghanistan
Schematic Cross Sections

Figure 5.1