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Groundwater Monitoring Program Plan and Conceptual Site Model for the Al-Tuwaitha Nuclear Research Center in Iraq

Prepared for the Radiation Protection Center of the Iraqi Ministry of Environment

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Abstract

The Radiation Protection Center of the Iraqi Ministry of Environment is developing a groundwater monitoring program (GMP) for the Al-Tuwaitha Nuclear Research Center located near Baghdad, Iraq. The Al-Tuwaitha Nuclear Research Center was established in about 1960 and is currently being cleaned-up and decommissioned by Iraq's Ministry of Science and Technology. This Groundwater Monitoring Program Plan (GMPP) and Conceptual Site Model (CSM) support the Radiation Protection Center by providing:

- A CSM describing the hydrogeologic regime and contaminant issues,
- recommendations for future groundwater characterization activities, and
- descriptions of the organizational elements of a groundwater monitoring program.

The Conceptual Site Model identifies a number of potential sources of groundwater contamination at Al-Tuwaitha. The model also identifies two water-bearing zones (a shallow groundwater zone and a regional aquifer). The depth to the shallow groundwater zone varies from approximately 7 to 10 meters (m) across the facility. The shallow groundwater zone is composed of a layer of silty sand and fine sand that does not extend laterally across the entire facility. An approximately 4-m thick layer of clay underlies the shallow groundwater zone. The depth to the regional aquifer varies from approximately 14 to 17 m across the facility. The regional aquifer is composed of interfingering layers of silty sand, fine-grained sand, and medium-grained sand. Based on the limited analyses described in this report, there is no severe contamination of the groundwater at Al-Tuwaitha with radioactive constituents. However, significant data gaps exist and this plan recommends the installation of additional groundwater monitoring wells and conducting additional types of radiological and chemical analyses.

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ACRONYMS AND ABBREVIATIONS

AOP	Administrative Operating Procedure
asl	above sea level
bgs	below ground surface
btoc	below top of casing
BH	borehole
BOS	bottom of screen
Bq/L	becquerels per liter
°C	Degrees Centigrade
CSM	Conceptual Site Model
DOS	Department of State, U.S.
DQO	data quality objective
EC	electrical conductivity (specific conductance)
EPA	Environmental Protection Agency, U.S.
FCL	Field Crew Leader
FOP	Field Operating Procedure
GMP	Groundwater Monitoring Program
GMPP	Groundwater Monitoring Program Plan
GOI	Government of Iraq
HASP	Health and Safety Plan
IAEA	International Atomic Energy Agency
IAEC	Iraqi Atomic Energy Commission
I.D.	Inner diameter
IRL	International Radioecology Laboratory
Km	kilometer(s)
LAMA	Active Metallurgy Testing Laboratory (Laboratoire d'essai Active Métallurgie)
m	meter(s)
mg/L	milligrams per liter
mm	millimeters
m^3	cubic meters
MCL	Maximum Contaminant Level
MoEN	Ministry of Environment
MoST	Ministry of Science and Technology
n.a.	not available
n.s.	no standard established
O.D.	Outer diameter
OP	Operating Procedure
PID	photoionization detector
PM	Program Manager
PPE	Personnel Protective Equipment
ppm	parts per million (equivalent to mg/L)
PVC	polyvinyl chloride
QA	Quality Assurance
QAPP	Quality Assurance Project Plan

QC	Quality Control
RPC	Radiation Protection Center
RWTS	Radioactive Waste Treatment Station
SAP	Sampling and Analysis Plan
SC	Sampling Coordinator
STP	Sewage Treatment Pond
SNL	Sandia National Laboratories
TDS	total dissolved solids
TL	task leader
TOC	top of casing
TOS	top of screen
U.S.	United States
μmohs/cm	micromohs per centimeter
VOCs	volatile organic compounds

1. INTRODUCTION

The Al-Tuwaitha Nuclear Research Center (hereafter referred to as Al-Tuwaitha) is located approximately three kilometers (km) south of the southern edge of Baghdad, Iraq. Al-Tuwaitha was established in about 1960 and became the principal nuclear facility in Iraq. By 1991, the facility consisted of 90 buildings. Al-Tuwaitha was heavily damaged by aerial bombings in 1991 and 2003. Research operations ceased in 1991 and the facility has been used for storage since then. A satellite image for October 2001 of the Al-Tuwaitha area is shown on Figure 1 (ESRI, 2011). Assessment, decontamination, and dismantlement of various buildings began in 2004; this work is being conducted by the Iraqi Decommissioning Program (Ministry of Science and Technology, 2011).

Groundwater studies began at Al-Tuwaitha in 2002 with the installation of six groundwater monitoring wells. In combination with the Iraqi Ministry of Science and Technology (MoST), the Radiation Protection Center (RPC) in the Iraqi Ministry of Environment (MoEN) resumed groundwater monitoring at the facility in 2011. In coordination with the International Atomic Energy Agency (IAEA), the U.S. Department of State (DOS) funded Sandia National Laboratories (SNL) to assist the RPC in establishing a Groundwater Monitoring Program (GMP) for Al-Tuwaitha. This GMP Plan (GMPP) and Conceptual Site Model (CSM) support the RPC by providing:

- A CSM of the hydrogeologic and contaminant issues,
- recommendations for future groundwater characterization activities, and
- descriptions of the organizational elements in a GMP.

This Al-Tuwaitha GMPP should be useful as a template for the Government of Iraq (GOI) to evaluate groundwater at other facilities with respect to protecting human health and mitigating potential impacts to the environment.

1.1 Goals

The GMPP goals for Al-Tuwaitha are to determine if prior activities have degraded the groundwater quality with respect to radiological contaminants, and to provide a groundwater quality baseline for evaluating the ongoing decontamination and decommissioning activities. This GMPP also establishes a management framework and presents the organizational elements of a GMP that could be readily implemented by the RPC.

1.2 Report Layout

The topics discussed below include: facility description and setting, potential sources for groundwater contamination, the CSM, data gaps, recommendations, and the organizational elements of a typical GMP.

Figure 1. Satellite Image, October 2001, of the Al-Tuwaitha Nuclear Research Center, Iraq (ESRI, 2011)

1.3 Applicable Regulations and Policies

In many countries, regulatory standards and guidance provide the foundation for groundwater monitoring and characterization programs. With the assistance of international partners advising through the IAEA, the GOI is preparing a new body of regulations for governing radiation protection, site cleanup, radioactive waste management, and the protection of groundwater resources. Given that the relevant Iraqi regulations are currently under development, this GMPP is based on SNL's best management practices for U.S. groundwater projects.

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2. FACILITY DESCRIPTION

Al-Tuwaitha is the largest and most complex nuclear facility in Iraq. By 1991, the research facility comprised 90 buildings dedicated to nuclear fuel fabrication, radiochemistry, uranium enrichment, plutonium and uranium processing, radioactive waste treatment, waste storage, and biological research (Chesser *et al*., 2009). Electrical power generation was not an operation. The buildings are shown on Figure 2 and are listed in Appendix A.

An approximately 4.6-km long, earthen security berm surrounds the facility. The berm is approximately 30 m high and contains three gaps which allow for vehicle access. For purposes of discussion, the berm surrounding the facility is used as the datum for measuring distances to features located outside Al-Tuwaitha. The facility (as defined by the area inside the earthen security berm) covers approximately 1.2 square km. Additional berm segments extend into the southwest quadrant of the facility.

2.1 Background Information

Three research reactors (Tammuz-1, Tammuz-2, and IRT-5000) were constructed at Al-Tuwaitha (Albright *et al.*, 1999). Eighteen buildings, including the reactors, were seriously damaged or destroyed by the aerial bombing in 1991. After 1991, some buildings were dismantled and several small buildings were constructed in their place. Several buildings were also damaged by the 2003 aerial bombing campaign. Extensive looting by local residents in 2003 resulted in significant damage to many of the buildings at Al-Tuwaitha. Depending on the level of destruction, the remains of a particular building may consist of collapsed roofs, standing walls, exposed foundations, or piles of rubble and debris. Significant progress in the last few years has involved the characterization, decontamination, and dismantlement of about 10 buildings including the LAMA (Active Metallurgy Testing Laboratory). The status of each building is listed in Appendix A.

In 2002, the former Iraqi Atomic Energy Commission (IAEC) collected the first round of groundwater samples at Al-Tuwaitha as the initial step for determining if radioactive materials had contaminated the groundwater beneath the facility (Abbas *et al*., 2010). In combination with MoST, the RPC resumed groundwater monitoring in 2011. This GMPP supports the ongoing groundwater monitoring effort.

Despite the long history of nuclear programs at Al-Tuwaitha, no significant radioactive contamination as a result of normal operations has been officially reported at Al-Tuwaitha or in the surrounding communities. Soil samples collected in 1991 by the IAEC did not contain radioactive contamination (Chesser *et al*., 2009). However, soil samples collected by a team of Iraqi and U.S. personnel in 2005 indicate that the 2003 aerial bombing dispersed radionuclides at several locations at Al-Tuwaitha (Chesser *et al*., 2009). Soil contamination was also attributed to improper waste handling practices. Radioactively contaminated soil was present at 10 locations with elevated uranium isotopes being the most common contaminant (Figure 3). Other elevated radionuclides were detected at four of the 10 sample locations, including cesium-137, strontium-90, cobalt-60, americium-241, plutonium-238, plutonium-239, plutonium-240, and various medical isotopes.

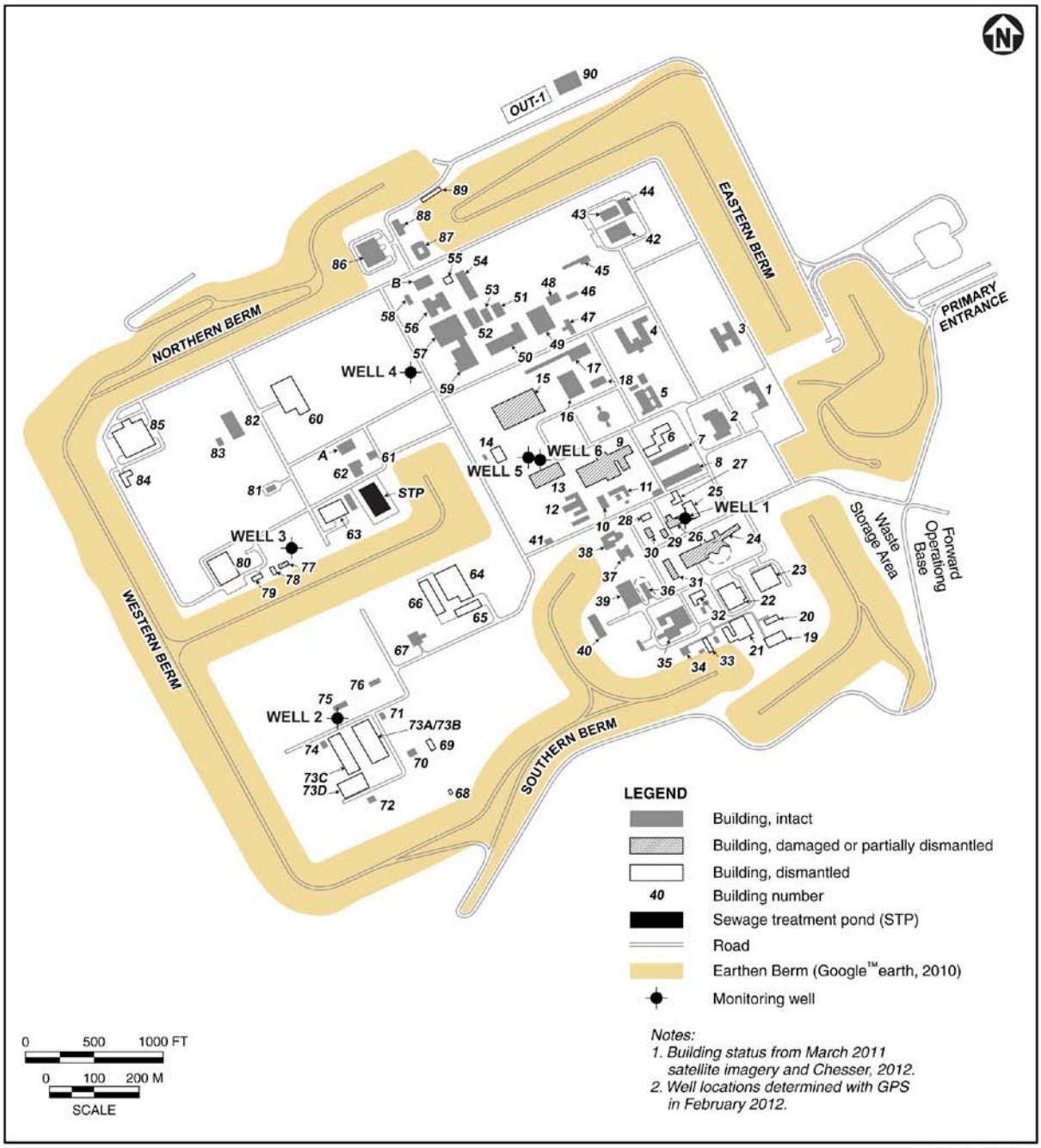

Figure 2. Buildings and Monitoring Wells Located at Al-Tuwaitha

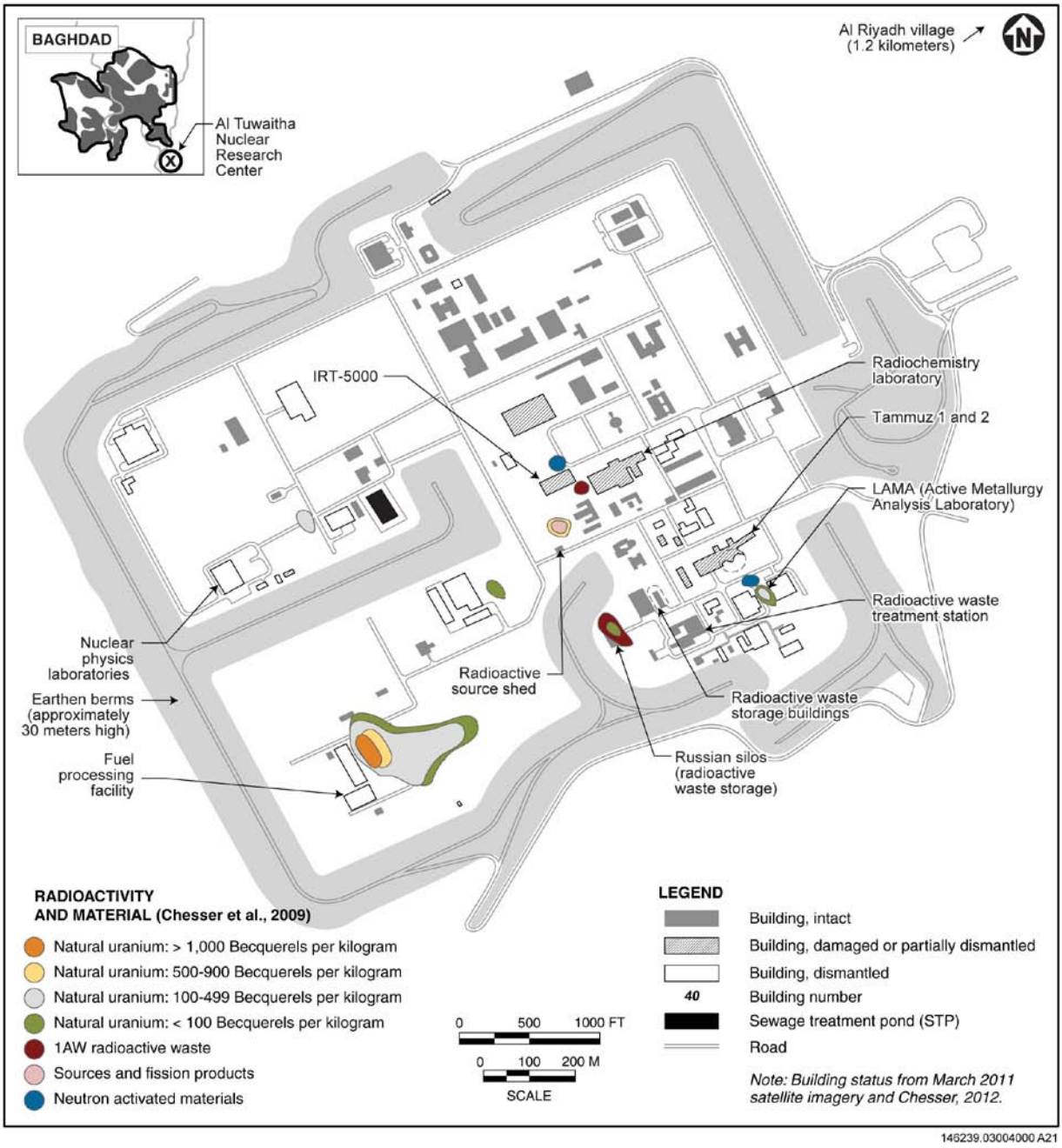

Figure 3. Radiologically Contaminated Soil at Al-Tuwaitha Based on Soil Samples Collected in 2005

Table 1 lists the estimated volumes of radioactive waste at 13 of the most used waste-storage buildings at Al-Tuwaitha (Al-Musawi, 2010). The total amount of solid radioactive waste is estimated to be 720 metric tonnes. The total volume of liquid radioactive waste is estimated to be approximately 155 cubic meters (m^3).

Table 1. Estimated Volumes of Solid and Liquid Radioactive Wastes at Al-Tuwaitha Buildings and Sites (Al-Musawi, 2010)

Building	Solid radioactive waste (metric tonnes)	Liquid radioactive waste (cubic meters)
Radioactive Waste Treatment Station (RWTS)	55	25
RWTS Warehouse	320	<1
Russian Silos	105	<1
Radiochemistry Laboratory	55	5
IRT-5000 reactor	85	55
Tammuz-2 reactor	50	35
Radioisotope Buildings I and II	30	35
Fuel Fabrication Building	10	<1
Scrap Yard (OUT-1)	10	<1
Building 85 (chemical research)	<1	<1
Solid Waste Storage Bunker	<1	<1
LAMA (Active Metallurgy Testing Laboratory)	<1	0
Radiochemistry Building	0	<1
Total, estimated	**720**	**155**

To summarize, Al-Tuwaitha was an Iraqi nuclear research facility that operated from about 1960 to 2003. Currently, there are radioactive materials, radiologically contaminated buildings, radioactively contaminated soils, and underground storage tanks containing liquid radioactive wastes as a result of past operating practices, two aerial bombings (1991 and 2003), and the 2003 looting. If not remediated, the debris and radioactive material, along with associated contaminated soil, pose a potential risk to site workers and the environment.

2.2 Current Facility Mission

Currently, the GOI is moving forward with facility assessment, decontamination, and building dismantlement based on the anticipated requirements of proposed Iraqi regulations. At Al-Tuwaitha, scrap metal and building debris are now being organized and stockpiled in temporary waste storage areas pending formal definitions of waste streams. Field data collection, development of laboratory analytical capacity, development of a radioactive waste management program, and regulatory oversight are all progressing along parallel pathways.

Significant progress in the last few years has involved the dismantlement of several buildings including the LAMA (Appendix A). However, much more work remains to be done at Al-Tuwaitha as it is estimated that removing all structures of concern and disposal of radioactive wastes will require at least 15 years (Chesser *et al*., 2009).

2.3 Regional Demographics

Al-Tuwaitha is located near the southern edge of Baghdad and within the Baghdad Governorate. Having a population estimated at six million (National Geographic, 2011), Baghdad is the largest city in Iraq and the second largest city in the Arab World after Cairo, Egypt. Located on the Tigris River, the city dates back to 762 A.D. The Baghdad Governorate is considered one of the more developed parts of Iraq, with a more sophisticated infrastructure than much of Iraq, although this infrastructure has been heavily damaged by military operations in the past 20 years and by continuing violence today.

Agriculture and oil production are important industries for Iraq. Besides the city of Baghdad, land use within 10 km of Al-Tuwaitha is predominately agricultural with scattered houses and villages in the outlying areas. The East Bagdad Oil Field is located approximately 10 km northeast of the facility. No oil fields or refineries are located in the immediate vicinity of Al-Tuwaitha. In the past decade, agricultural operations have increased in the vicinity of Al-Tuwaitha. Also, more drainage ditches and homes have been built surrounding the facility.

2.4 Physical Setting

The Republic of Iraq is located in the Middle East and is bordered by Jordan to the west, Syria to the northwest, Turkey to the north, Iran to the east, and Kuwait and Saudi Arabia to the south. Iraq covers approximately 438,000 square km and is the 58th largest country in the world. The capital city, Baghdad, is located near the geographic center of the country. Two major rivers, the Tigris and Euphrates, extend across the center of Iraq flowing from approximately northwest to southeast before discharging into the Persian Gulf. The rivers provide Iraq with agriculturally capable land along the Mesopotamian Plain, which is in stark contrast with the barren desert landscape that covers most of Iraq. Both rivers are fed by snow pack and rainfall in eastern Turkey and northwest Iran. The Tigris River passes near Al-Tuwaitha. Near Baghdad, the Mesopotamian Plain is approximately 300 km wide and is characterized by low topographic relief. Outside the influence of the Tigris River, the surrounding area is dominated by flat lying desert scrublands of the Mesopotamian Shrub Desert terrestrial ecoregion (MoEN, 2010).

The fertile soils on the Mesopotamian Plain are an important resource for Iraq. Due to the arid climate, irrigation is essential for producing reliable and sizable crop yields for a growing population. However, the excess use of irrigation water has been detrimental at many locations across the plain. For centuries, Iraq has been plagued by highly saline soils that drain poorly. Over-watering of fields and orchards can raise the groundwater levels to the critical depth where salt accumulation in the soil impedes root growth. Therefore, saltwater management is practiced in Iraq. Drainage ditches are typically used to maintain groundwater levels and prevent water-logging of the soil horizons (Ministry of Water Resources, 2006). Shallow groundwater levels are also lowered by the use of drainage ditches, dewatering wells, and subsurface drainage pipes. The pumped groundwater is typically discharged to ponds and allowed to evaporate.

The Tigris River is approximately 1,718 km long of which 1,415 km lies within Iraq (Jassim and Goff, 2006). The river is typically silt-laden. The spring flood period occurs from February through June and can comprise 60 to 80 percent of the total annual flow across Iraq (Food and Agriculture Organization, 2011). The Tigris River meanders through the center of Baghdad and

during 1976 and 1977 had an average depth that ranged from 9.5 to 12.2 m (Al-Ansari *et al*., 1979). The river was well channelized and varied in width from 180 to 330 m. The water elevations varied by 4.1 m throughout the brief measurement period (June 1976 to September 1977) at both of the gauging stations in Baghdad. On average, approximately 46.4 percent of the annual flow of the Tigris River occurs in just three months (March, April, and May). For the period of 1930 to 2004, the average discharge rate of the Tigris River in Baghdad was 1,020 m^3 per second (Saleh, 2010). Peak flow of the Tigris River typically occurs in May.

Water quality of the Tigris River near Baghdad is affected by several factors including irrigation runoff, adjacent sediments, and sewage discharges. The measurements of water quality in the river is dependent on spatial (sampling location) and temporal (flow rate) effects. Few references are available. In 1978, the Tigris River near the southern edge of Baghdad had a salinity of 443 milligrams per liter (mg/L) (Mutlak *et al.,* 1980), which is near the upper limit of 500 mg/L for what is considered fresh water. In 2008, four pumping stations in Baghdad routinely discharged untreated sewage water into the Tigris River (Razzah *et al*., 2009). At least two water-intake stations on the Tigris River in Bagdad were in service during 2008.

2.4.1 Climate

Al-Tuwaitha is characterized by a hot, arid climate with intense sunshine for much of the year. In terms of maximum temperatures, nearby Baghdad is considered one of the hottest cities in the world. July is the warmest month with an average high of 44 Centigrade (°C) and an average low of 25.5°C. January is typically the coolest month with an average high of 16°C and an average low of 3.8°C. Days with freezing temperatures are rare. Throughout the year, the high temperature averages 30.6°C and the low temperature averages 14.9°C.

The mean annual rainfall in Baghdad is 152 millimeters (mm) (Al-Adili and Ali, 2006). Rainfall primarily occurs during November through April, and has varied from a high of 575 mm per year to as low as 23 mm per year. Rainfall is almost completely unknown in the summer. However, since the humidity is very low (usually under 10 percent) during the summer, dust storms commonly occur. The region has clear skies during most of the year and potential evaporation rates are high, exceeding 2,000 mm in the summer (Hasson, 2008). The prevailing wind direction is from the northwest.

2.4.2 Regional Geology and Hydrogeology

The Mesopotamian Plain is covered with Quaternary-age alluvial deposits that are as much as 80 m thick near Baghdad (Jassim and Goff, 2006). The deposits are composed of alternating layers of clay, silt, sand, and occasional gravel. Thicknesses and lateral extents of the various stratigraphic layers are variable across the plain. Stratigraphic discontinuities, both laterally and vertical, are common. Regional groundwater flows derived from the distant mountainous regions ascend toward the land surface in the Mesopotamian basin. As a result, the Mesopotamian Plain is a regional discharge zone for the Mesopotamian Aquifer Megasystem.

Three types of groundwater occurrences, as discussed in Jassim and Goff (2006), are applicable to the hydrogeologic regime at Al-Tuwaitha:

(1). Seasonal fluctuations in the water table can occur in narrow segments along rivers and canals. In the winter and spring, the water table rises due to recharge from the combined effects of precipitation, high water levels in streams and rivers, and irrigation water in the canals. Groundwater levels decline in the dry summer and autumn months. Throughout the year, typical water-table fluctuations can range from 1 to 10 m near the rivers with decreasing amounts of fluctuations away from the river.

(2). Shallow perched water-table aquifers are occasionally present within impermeable layers above the regional potentiometric surface. The perched aquifers can be under semi-confined or confined conditions.

(3). Deep wells completed the regional aquifer are often under confined conditions and can be artesian.

Soils in the vicinity of Baghdad are alluvial in origin with variable thicknesses ranging from 0.4 to 4 m (Al-Adili and Ali, 2006). The soils are relatively saline as a result of being derived from parent materials containing significant amounts of gypsum and salts (mostly chlorides and sulfates). The soils are generally underlain by clay, silty clay, or clayey silt, with occasional sand lenses. Shallow groundwater with a potentiometric surface ranging from 0.5 to 3 m is attributed to the combined effect of nearby rivers, high population density, and long-term agricultural operations. Al-Adili and Ali (2006) determined that the amount of rainfall that infiltrated to groundwater was only 4.8 mm, approximately three percent, of the mean annual precipitation. At a geological test borehole located 2.3 km southeast of Al-Tuwaitha, 14 m of clay and silty clay were encountered; no sandy units capable of supplying useful quantities of water were noted (Abbas *et al*., 2008).

Using 16 water wells, each with an approximate depth of 12 m, Al-Adili and Ali (2006) prepared a potentiometric-surface map for an 850 square km area surrounding Baghdad and to the north of Al-Tuwaitha. The water elevations were measured in February 1996, which coincided with the ending of the wet season. The aquifer east of the Tigris River was interpreted to be under semi-confined conditions and overlain by an extensive clay horizon. The Tigris River was a gaining stream at that time, meaning that the aquifer was discharging water to the river.

Abbas *et al*., (2008) presented a map for the eastern bank of the Tigris River showing that 11 water-supply wells were located within 9.5 km of Al-Tuwaitha. The nearest water-supply well was located approximately 2.6 km south of the facility. The wells ranged in depth from 23 to 60.6 m. Static water levels in the wells were within 1.2 to 7.5 m of the ground surface indicating that the wells were screened in stratigraphic units under either confined or semi-confined conditions (i.e., the wells had positive pressure heads). Water-quality data for well 8047 was the most comprehensive of the 11 wells; the well was located approximately 2.8 km south of the facility with a total depth of 24 m. The well yield was 778 m^3 (778,000 liters) of water per day. The concentration of total dissolved solids (TDS) was 10,929 parts per million (ppm) which was far above the criterion of 5,000 ppm at which water is considered saline.

Values for groundwater velocities are not cited in the available literature for the Bagdad region. However, an estimate was calculated using aquifer-testing data for off-site water-supply well 8047. That well is completed in an undefined unit with a hydraulic conductivity of 10.4 m/day

(Abbas *et al*., 2008). This hydraulic conductivity value is typical of medium-grained sand (Heath, 1989). By assuming an effective porosity of 20 percent and inferring an approximate gradient between Well 8047 and Well 3912 of 0.001 m/m (Abbas *et al*., 2008), the calculated groundwater velocity is 0.05 m/day westward. Properly known as seepage velocity, this value represent the velocity of groundwater moving through pore spaces in the sand. However, the effects of nearby water-supply wells upon the aquifer and the resultant temporal changes in gradients and velocities are not known.

2.4.3 Local Surface Water Features

Al-Tuwaitha is located downstream of Baghdad and approximately 0.8 km to the east of the Tigris River. Near the facility, the river is approximately 200 to 300 m wide. Three water-diversion pump stations are located near Al-Tuwaitha (DigitalGlobe, 2011). The northern pump station is located upstream and approximately 1 km northwest of Al-Tuwaitha on the eastern bank of the Tigris River. The northern pump station and nearby holding pond were in operation in July 2002 and may have supplied water to Al-Tuwaitha. The pump station also appears to have supplied a minor amount of irrigation water to fields. The holding pond had a surface area of 6,600 square meters (m^2) and was apparently connected to underground piping. The northern pump station was probably not operational during November 2003 to August 2009. However, the northern pump station was operational again in March 2011. The other two pump stations are located 2.2 km and 2.9 km southwest of Al-Tuwaitha on the west bank of the Tigris River. These two pump stations discharged water to open channels that were used for irrigating orchards and croplands. The southern pump stations were operational during October 2001 to March 2011.

Based on a review of satellite imagery, an extensive system of irrigation and drainage ditches surround the Al-Tuwaitha facility (Google Earth, 2010 and DigitalGlobe, 2011). Date palm orchards are located along the eastern bank of the Tigris River and are located approximately 0.3 km to the west of the facility. Orchards and croplands, presumably for barley or wheat, are located approximately 0.8 km to the southwest of the facility. The area to the north, east, and south of Al-Tuwaitha consisted of inactive (fallow) cropland in 2002 to 2011. A group of shallow earthen basins located approximately 2 km south of Al-Tuwaitha are fish-harvesting ponds (Al-Jiburi 2011).

In 2002, the Tigris River near Al-Tuwaitha had a high-water stage of 34.44 m above sea level (asl) in the spring and a low-water stage of 25.21 m asl in the summer (Abbas *et al*., 2010a). The resulting difference in the stage heights was 9.23 m. The Tigris River is well channelized near Al-Tuwaitha but no large-scale levees are apparent on satellite imagery. The maximum depth of the Tigris River near Al-Tuwaitha is probably on the order of 10 m during a typical year.

No perennial surface water features are currently known to be located at Al-Tuwaitha. The Tigris River is the only perennial surface-water body located near the facility. Since 2002, small ponds of undetermined status (possibly sewage disposal) were present on the southern edge of the village of Al Ridyah. The ponds were located approximately 1.4 to 2.5 km to the northeast of Al-Tuwaitha (Google Earth, 2011). Several large excavations located at the Ash Shaykili Warehouse Complex near Al Riyadh contained standing water (possibly sewage) in 2009. The complex was located approximately 2 km northeast of Al-Tuwaitha.

During October 2001 to July 2002, a sewage treatment pond (STP) with standing water and green vegetation was visible on the satellite imagery near Building 62 (the sewage treatment plant) at Al-Tuwaitha (Figures 1 and 2). The pond covered 1,500 m^2. The pond and nearby open-air settling tanks appear to have last been used in July 2002.

Irrigation and drainage waters are most likely ephemeral in the ditches and drainage channels near Al-Tuwaitha. Few details are available concerning the potential for surface-water runoff to occur on-site at Al-Tuwaitha. No large-scale surface-water channels or diversion ditches are apparent on the satellite imagery. Due to the arid climate, the potential for surface-water runoff is minimal.

2.4.4 Water Usage and Disposal at Al-Tuwaitha

Water usage and disposal at Al-Tuwaitha is not well documented. However, several findings obtained from excerpts of U.N. inspector reports (Albright *et al*., 1999) are applicable.

- Building 45 was the water treatment station.
- Building 62 was the sewage station.
- Building 67 contained deionized water production units.
- Building 31 contained the cooling towers for the Tammuz-2 reactor.

A sizeable water distribution network was probably used at Al-Tuwaitha for drinking water, landscape irrigation, and research purposes until about 1991. The recent status of the network is not documented. Water-supply wells may have been located near Building 45 but the better quality water from the Tigris River via the northern pump station may have been more useful. If present, the production wells might have supplied backup capacity. As mentioned above, the northern pump station was probably connected to Building 45 via underground piping.

A variety of other wells may be present at or near Al-Tuwaitha. With some of the larger buildings having basements and underground material-transfer channels, dewatering wells (sumps) may have been used. Saturated sediments (the shallow groundwater zone) are present at a depth of approximately 7 m at some locations inside the berm. The presence of off-site water-supply wells in the vicinity of Al-Tuwaitha is not well documented. As mentioned earlier, 11 water-supply wells are located in the vicinity of the facility. However, hand-dug water wells may exist in the immediate vicinity of Al-Tuwaitha. Such wells would most likely not be documented and a field survey would be needed to verify the presence, or lack of, such wells. Well records for some water-supply wells may be lacking and were therefore not listed in Abbas *et al*., (2008). Dewatering wells for agricultural operations and salt control may be present too.

At other nuclear facilities worldwide, several types of water discharges and disposals such as buried leach fields, sumps, and seepage (disposal) ponds have impacted groundwater. Whether or not these types of activities are a concern for Al-Tuwaitha is worthy of further study. Several questions are applicable for Al-Tuwaitha:

- Besides the STP discussed above, were other sewage ponds used?
- Were all of the buildings connected to a single facility-wide sewage system that connected to Building 62?
- Were individual leach fields, sumps, or cesspools used at some buildings?
- Were sanitary wastes (from bathrooms) and waste waters (from laboratories, reactors, fuel processing, etc.) connected to the same sewage water-disposal system?
- Were separate systems used for the different types of water?

2.4.5 Hydrogeology of Al-Tuwaitha

This GMPP is based on a limited amount of site-specific hydrogeologic data that were collected in 2002 and 2011. In 2002, the IAEC conducted a hydrogeologic study that consisted of installing and sampling six groundwater monitoring wells (Wells 1 through 6) as listed in Table 2. According to Abbas *et al.*, (2010a), the well locations were selected for the purpose of characterizing the groundwater near the facilities of greatest concern: the IRT-5000 reactor (Building 13), the Tammuz-2 reactor (Building 24), the radiochemistry laboratory (Building 9), the nuclear physic laboratory (Building 80), and the fuel processing facility (Building 73). A monitoring well was also installed at an assumed background (uncontaminated) area west of Building 57. The six monitoring wells are listed in Table 2 with respective to the corresponding buildings and are shown on Figure 2.

Table 2. Construction Details for Monitoring Wells Installed at Al-Tuwaitha in 2002 (Abbas *et al*., 2010a)

Monitoring Well	TOS (m, bgs)	BOS (m, bgs)	Pipe size, I.D., inches	Pipe size, O.D., inches	Screened unit	Borehole TD (m, bgs)	TOC Elevation (m, bgs)	Stick-up*	Ground Surface Elevation * (m, asl)	Building of concern
Well 1	6	12	4.5	4.75	Shallow groundwater zone	15	32.02	0.51	31.51	Building 24 (TAMMUZ-2 reactor)
Well 2	6	12	4.5	4.75	Isolated lens	15	31.88	0.68	31.20	Building 73 (fuel processing facility)
Well 3	13	23	4.5	4.75	Regional Aquifer	26	31.56	0.52	31.04	Building 80 (nuclear physics laboratory)
Well 4	12	24	4.5	4.75	Regional	27	31.81	0.17	31.64	Assumed background area
Well 5	6	12	4.5	4.75	Shallow groundwater zone	15	31.59	0.31	31.28	Building 13 (IRT-5000 reactor)
Well 6	24	42	4.5	4.75	Regional Aquifer	45	31.57	0.25	31.32	Building 9 (radiochemistry laboratory)

*TOC elevations were surveyed, but ground surface elevations were not provided by Abbas *et al*., (2010a). The vertical distance (stick-up) between the TOC and the ground surface at each well was measured in February 2012 and was used to calculate the ground surface elevations; coordinates (latitude and longitude) were determined using a global positioning system-enabled Canon camera model SX 230 HS; diameters of carbon steel pipe were measured with a ruler (Lum, 2012a and 2012b).

asl = above sea level
bgs = below ground surface
botc = below top of casing
BH = borehole
BOS = bottom of screen
I.D. = inner diameter
m = meters
O.D. = outer diameter
TD = total depth
TOC = top of casing
TOS = top of screen

As shown in Table 2, the six monitoring wells range in depth from 12 to 42 meters (m) with screen lengths varying from 6 to 18 m (Abbas *et al*., 2010a). In 2002, the drill cuttings were logged to a maximum depth of 45 m below ground surface (bgs). The wells are constructed of carbon-steel pipe with a 4.5-inch inner diameter (I.D.) and a 4.75-inch outside diameter (O.D) (Lum 2012a). These dimensions probably correspond to standardized American Petroleum Institute dimensions. The wells were installed in a series of 10-inch (25.4 centimeter) diameter boreholes and were developed with an air compressor. Specific data concerning the drilling method and well-construction details are not available and a possibility exists that a very low yielding, shallow (unconfined) water-bearing zone representing the water table was not recognized. Also, thin stratigraphic units may not have been recognized during the drilling activity.

Figures 4 and 5 are hydrogeologic cross-sections that were constructed using the lithologic descriptions (Appendix B) from Abbas *et al*., (2010a) for the six drilling locations. Cross-sections A-A′ (Figure 4) and B-B′ (Figure 5) trend from northwest to southeast and from southwest to northeast, respectively. The cross-sections show that low permeable materials comprise the uppermost 7 to 18 m of strata and consist of loamy and clayey soil underlain by interfingering layers of light brown clay, silt, and silty clay. The light brown clay is laterally extensive and serves as an aquitard above both the shallow groundwater zone and the regional aquifer. In the eastern part of the facility, the shallow groundwater zone consists of 3 to 4 m of grey silt and fine sand. The shallow groundwater zone pinches out and is not present in the western half of the facility. Starting at depths varying from 14 to 16 m across the facility, the regional aquifer consists of grey silt and fine sand. At Well 6, the regional aquifer material coarsens downward to medium-grained sand. The thickness of the regional aquifer is at least 31 m, but the lower boundary was not determined. The regional aquifer appears, however, to extend across the entire facility.

The shallow groundwater zone has a positive pressure head as evidenced by the water levels in Well 1 and Well 5 rising approximately 4.5 and 6.2 m, respectively, above the water producing zone (screened interval). The overlying low permeable sediments function as an aquitard. Because of the stratigraphic discontinuities in the overlying sediments, the shallow groundwater zone is interpreted to be under semi-confined conditions. The regional aquifer also has a positive pressure head as evidenced by the range of water levels in Wells 3, 4, and 6 rising approximately 12.7 to 19 m above the respective screened intervals. The low permeable sediments between the shallow groundwater zone and the regional aquifer serve as an aquitard with the regional aquifer also being interpreted to be under semi-confined conditions.

The statement that groundwater exists as shallow as 4 m across the site (Abbas *et al*., 2010a) requires some clarification. The top of the respective stratigraphic unit is actually the depth where groundwater first occurs. As shown on the cross-sections, the depth to the shallow groundwater zone (the top of the grey silt to fine-sand stratigraphic unit) varies from approximately 7 to 9 m where present in the eastern part of the facility. This distance (7 to 9 m) is the actual depth to groundwater. Because the groundwater is semi-confined, groundwater does have the potential to rise upwards in a well or trench to depths as shallow as 4 m, which is the potentiometric surface.

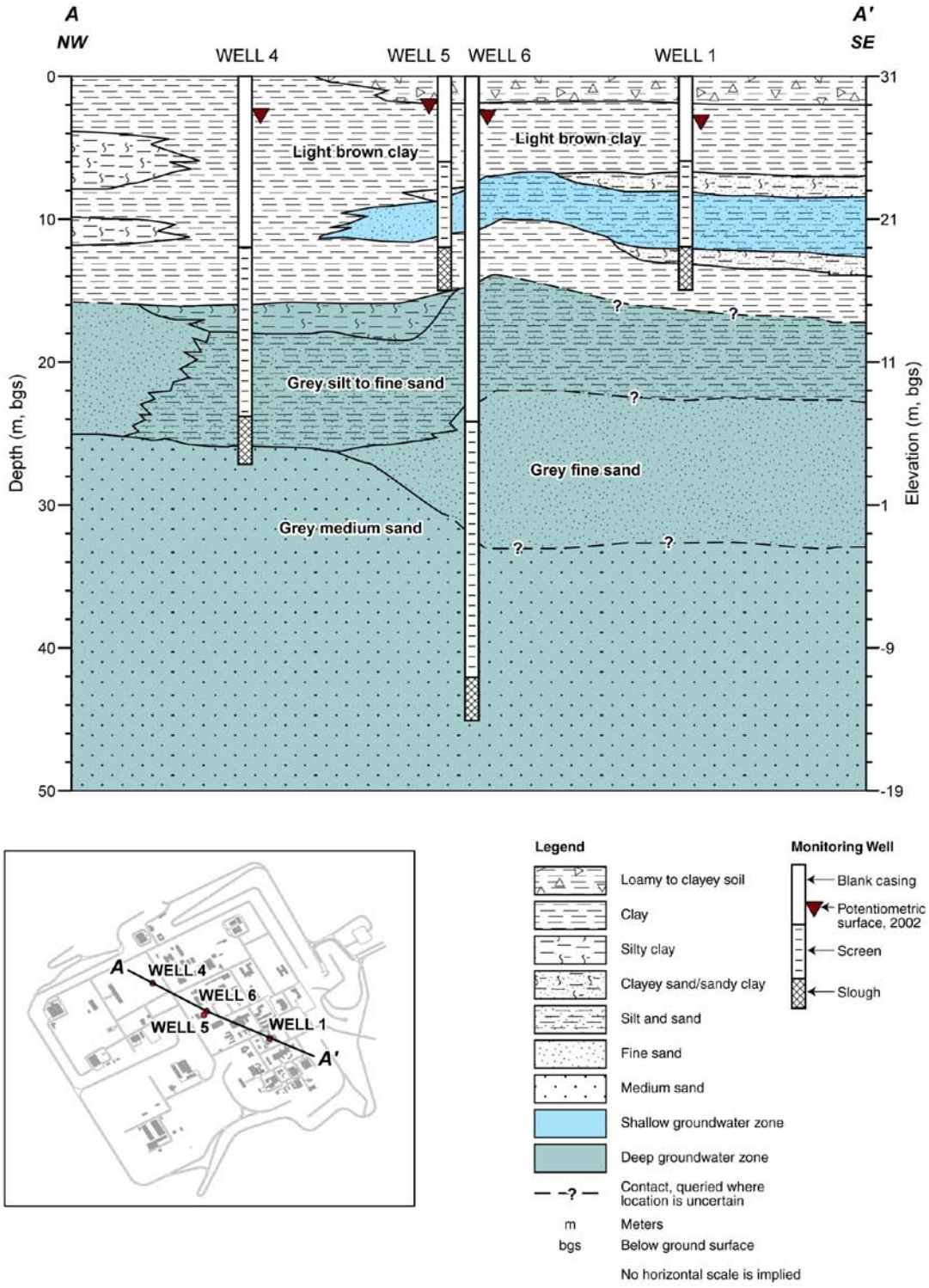

Figure 4. Hydrogeologic Cross Section A-A′ for Al-Tuwaitha Constructed using Lithologic Descriptions from Abbas *et al*., (2010a)

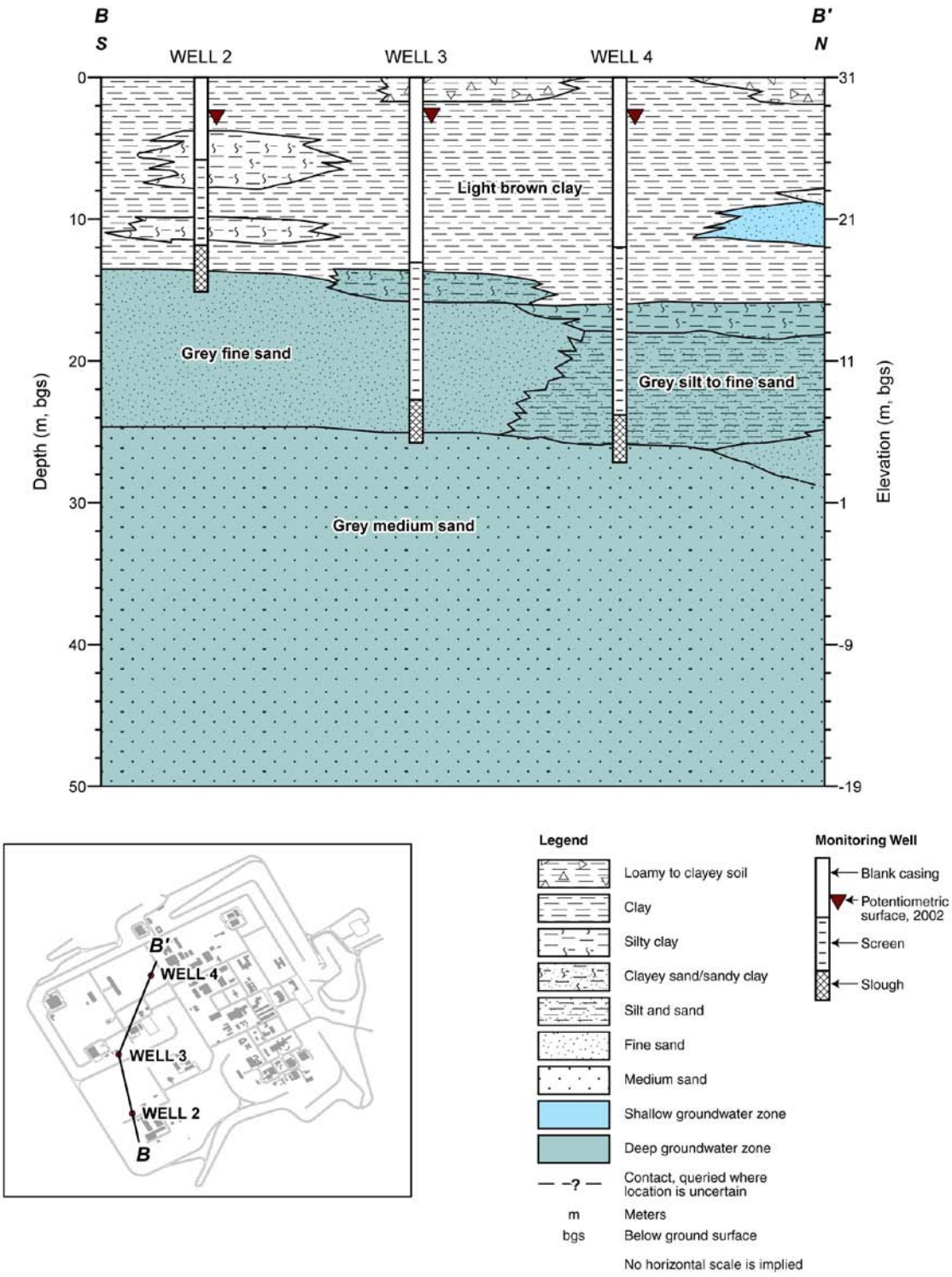

Figure 5. Hydrogeologic Cross Section B-B′ for Al-Tuwaitha Constructed using Lithologic Descriptions from Abbas *et al*., (2010a)

Water levels have been measured in the six monitoring wells during five events at Al-Tuwaitha, once in 2002 and four times in 2011 (Appendix C). As shown in Table 2, three wells (3, 4, and 6) are screened in the regional aquifer, two wells (1 and 5), are screened in the shallow groundwater zone, and Well 2 is screened in an isolated lens of silty clay.

Figure 6 depicts the July 2011 potentiometric surface contours for the regional aquifer. The groundwater elevations for Wells 3, 4, and 6 varied from 26.37 to 26.67 m asl. The horizontal gradient of the regional aquifer is inferred from the contours to be approximately 0.0006 m/m to the southwest. Because of the flatness of the potentiometric surface, minor errors in the surveyed elevation of the tops of casing would make significant changes in this interpretation.

Calculating the groundwater flow direction and gradient for the shallow groundwater zone is not as precise because only two monitoring wells (Wells 1 and 5) are screened in the shallow groundwater zone (the grey silt and sand). As shown on cross-section B-B′ (Figure 5), Well 2 is screened in an isolated lens of silty clay and is therefore not contoured with the other wells. Therefore, a three-point solution could not be calculated for the shallow groundwater zone using just the two wells. In July 2011, the groundwater elevations for Wells 1 and 5 were 26.50 and 25.88 m asl, respectively. Using these two measurements, groundwater in the shallow groundwater zone is inferred to be flowing generally northwestward at a horizontal gradient of approximately 0.002 m/m.

Figure 7 depicts the December 2011 potentiometric surface contours for the regional aquifer. The groundwater elevations for Wells 3, 4, and 6 varied from 26.84 to 27.05 m asl. The horizontal gradient of the regional aquifer is inferred to be approximately 0.0004 m/m to the southwest. Figure 7 also depicts the December 2011 potentiometric surface for the shallow groundwater zone. The groundwater elevations for Well 1 and Well 5 were 26.72 and 26.26 m asl, respectively. Groundwater in the shallow groundwater zone is inferred to be flowing generally northwestward with a horizontal gradient of approximately 0.001 m/m.

Figures 6 and 7 are considered to be representative of the water levels for the summer and winter of 2011, respectively. As shown by the potentiometric surface contours, the groundwater appears to flow at a consistent rate and direction in both water-bearing zones, regardless of the season. No significant changes in flow direction or gradient are apparent.

From 2002 to 2011, groundwater levels declined at each of the six monitoring wells. The average decline was 1.4 m. As shown on the hydrograph (Figure 8), the 2011 groundwater levels in the six wells fluctuated uniformly in a pattern that most likely correlated to seasonal effects (typical wetter winter months followed by drier summer months). No groundwater pumping is known to occur at or near Al-Tuwaitha. During 2011, the groundwater levels fluctuated within a narrow range of elevations varying from 25.67 to 26.72 m asl for the shallow groundwater zone and 26.20 to 27.05 m asl for the regional aquifer (Appendix C). The groundwater elevation at stratigraphically isolated Well 2 varied from 26.01 to 26.69 m asl during 2011.

Wells 5 and 6 are located approximately 20 m apart and were used for calculating vertical gradients. For the four 2011 measurement events, the vertical gradient at the well pair averaged approximately 0.04 m/m. The gradient was consistently upwards.

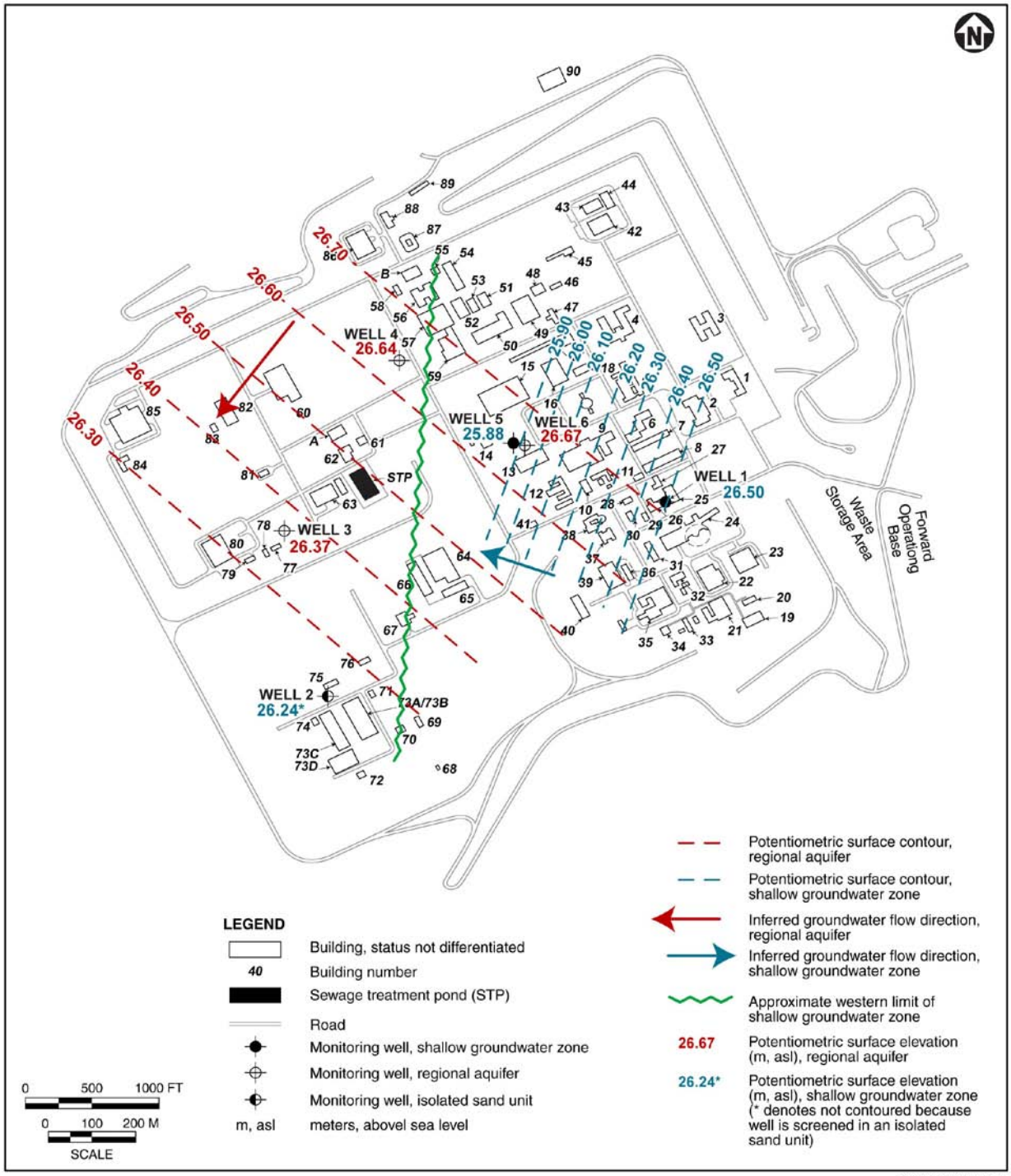

Figure 6. Potentiometric Surface Map (13 July 2011) for the Shallow Groundwater Zone and the Regional Aquifer at Al-Tuwaitha

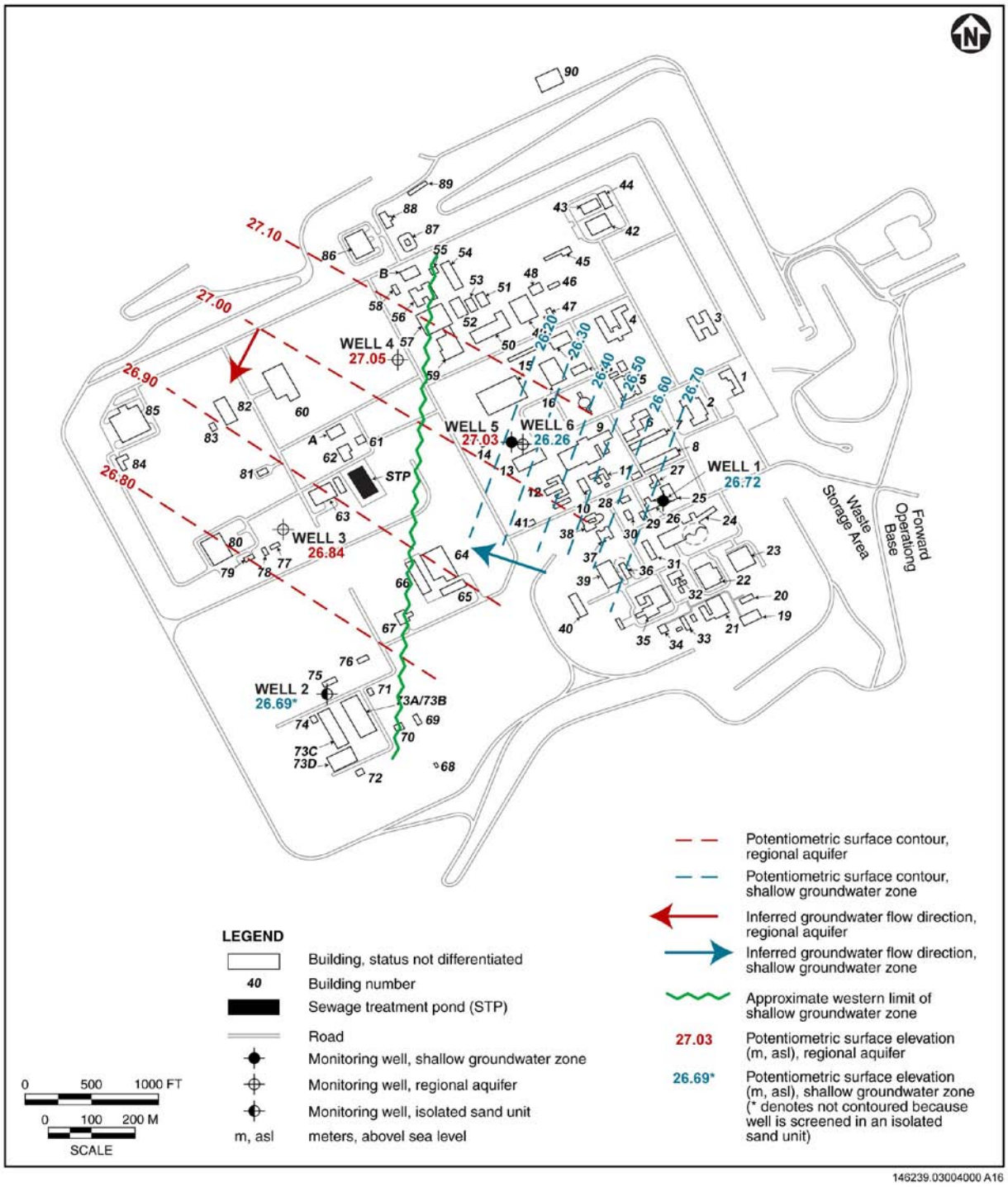

Figure 7. Potentiometric Surface Map (12 December 2011) for the Shallow Groundwater Zone and the Regional Aquifer at Al-Tuwaitha

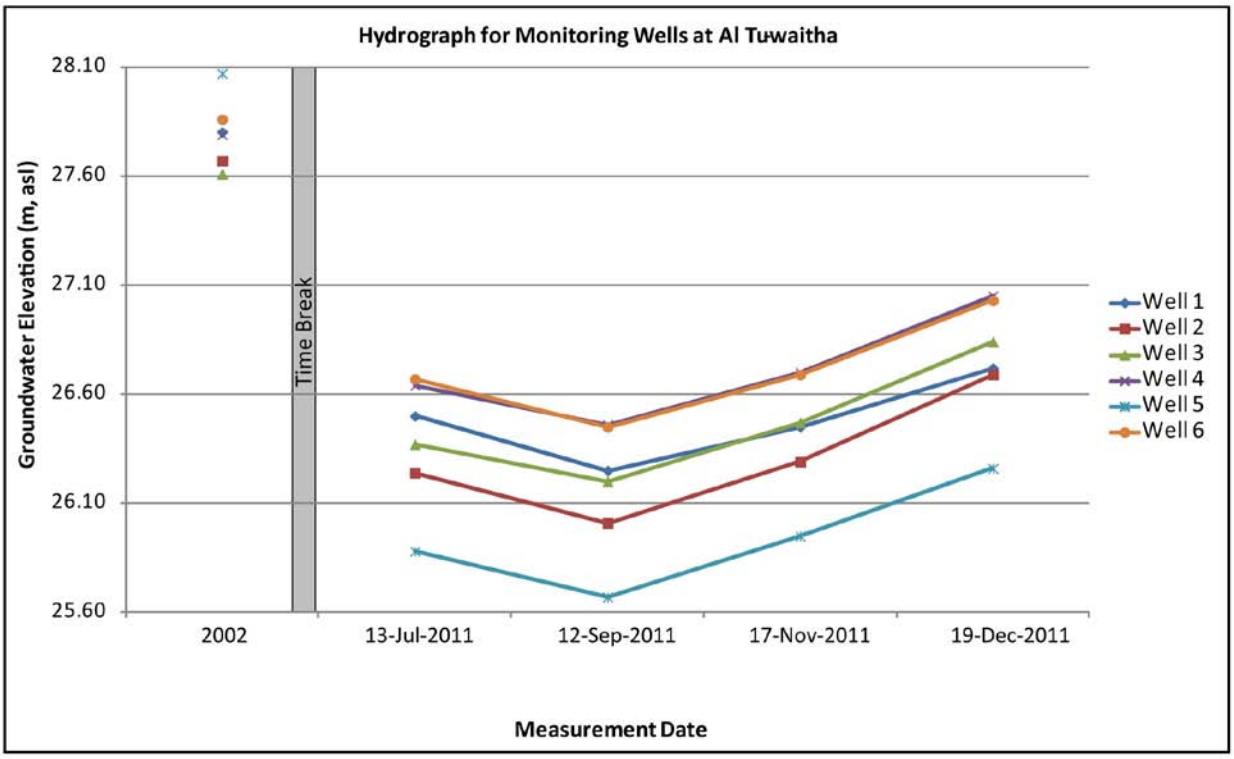

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Figure 8. Hydrograph of Groundwater Elevations Measured in 2002 and 2011

The 2002 potentiometric surface contours for the regional aquifer are shown on Figure 9. The precise date of water-level measurement in 2002 is not known. Contours for the shallow groundwater zone are not shown because the water levels at Wells 1 and 5 are considered to be anomalous when compared to the four events in 2011. For the single event in 2002, the water level in Well 5 was higher than Well 1. However, during all four events in 2011, the water level in Well 1 was consistently higher than Well 5. The disparity between the 2002 and 2011 data suggests that the water levels in Wells 1 and 5 had not fully stabilized after well installation and before the measurement of water elevations in 2002.

During 2011, the regional aquifer had a horizontal gradient that was an order of magnitude less than the shallow groundwater zone. The gradient of the regional aquifer was 0.0006 and 0.0004 m/m in July and December 2011, respectively, and was consistently to the southwest. The gradient of the shallow groundwater zone was 0.002 and 0.001 m/m in July and December 2011, respectively, and was consistently to the northwest. Because Al-Tuwaitha is located in a bend of the Tigris River, groundwater in both water-bearing zones flows towards the river.

The extensive clay layer above the regional aquifer is most likely an aquitard that limits the vertical migration of groundwater between the aquifer and the river. It is not known if the regional aquifer extends as far westward as the Tigris River, which is located approximately 0.8 km west of the facility.

The low horizontal gradients in the two water-bearing zones mimic the low topographic relief. As a result, groundwater velocities are expected to be consistently low. However, site-specific aquifer tests, such as slug tests with properly designed and constructed wells, are needed for accurate gradient and velocity calculations to be made.

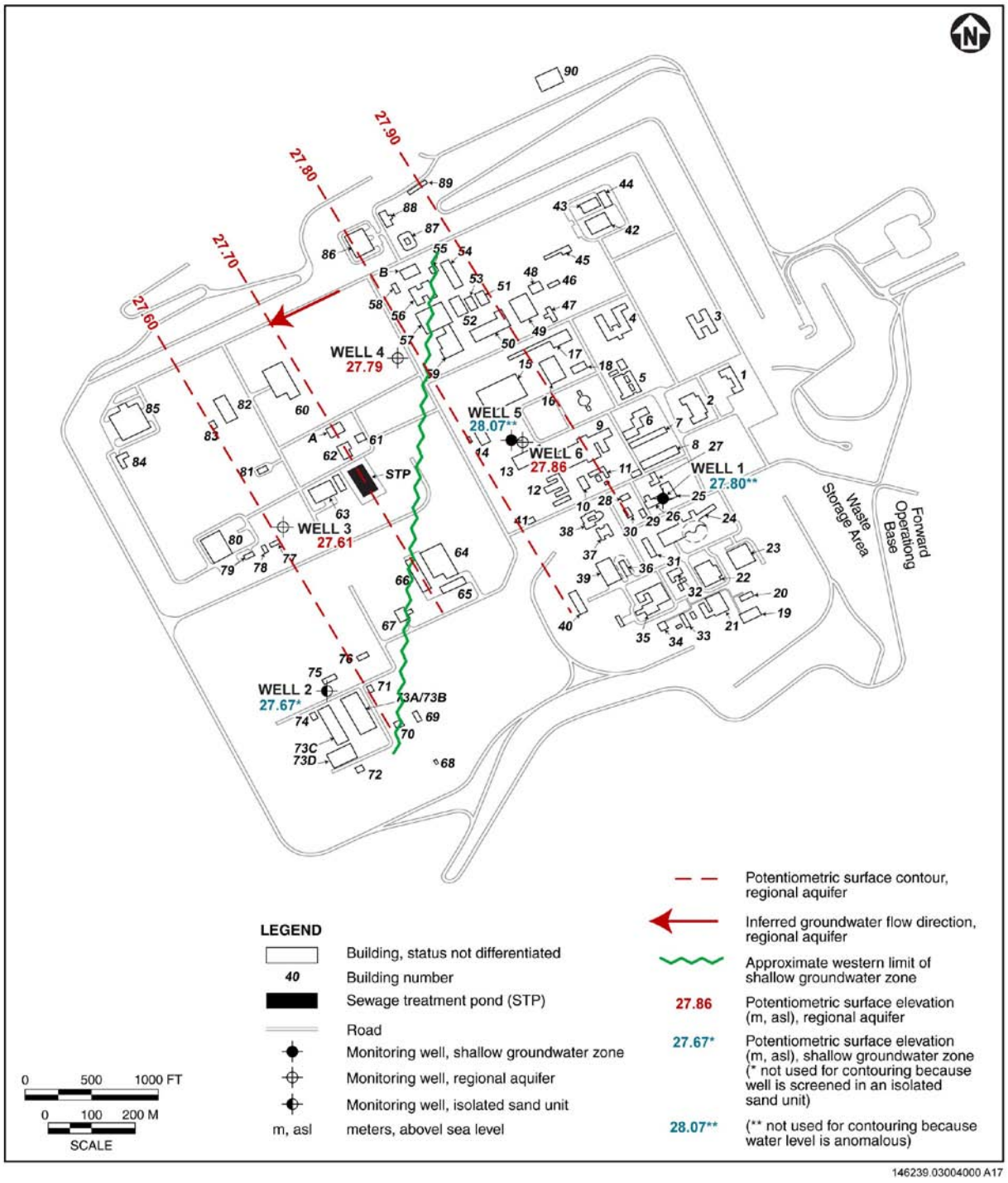

Figure 9. Potentiometric Surface Map (unspecified date in 2002) for the Regional Aquifer at Al-Tuwaitha

2.4.6 Groundwater Quality at Al-Tuwaitha

In 2002, the former IAEC conducted the first groundwater sampling event at Al-Tuwaitha (Abbas *et al*., 2010a). Groundwater samples were collected at all six of the monitoring wells (Well 1 through Well 6) on an unspecified date in 2002. The groundwater samples were analyzed for eleven parameters: pH, specific conductance, TDS, four cations (Ca, Mg, Na, and K), and four anions (Cl, HCO_3, SO_4, and NO_3). The geochemical results for 2002 are summarized in Tables 3 and 4, and are graphically depicted on the Stiff diagrams presented on Figure 10. In order to reduce the possible bias of stratigraphic interpretation, the wells are discussed below using the categories of shallow versus deep wells. Wells 1, 2, and 5 (the shallow wells) have similar Stiff diagrams. As a group, Wells 3, 4, and 6 (the deeper regional wells) have similar Stiff diagrams that are distinctive from the shallow wells. The two differing sets of the geochemical signatures suggest that the shallow wells and the deeper regional wells are not hydraulically connected.

Groundwater samples collected in 2002 had the following geochemical characteristics:

- The shallow wells had slightly higher pH (7.70 – 7.80) than the deeper regional wells (7.30 – 7.42).
- The shallow wells had higher electrical conductivity (EC) (10,660 – 13,000 micromohs per centimeter (μmhos/cm) than the deeper regional wells (2,820 – 4,610 μmhos/cm).
- The shallow wells had higher TDS concentrations (6,864 – 18,364 mg/L) than the deeper regional wells (1,830 – 2,985 mg/L).

Additional groundwater samples were collected during three events in 2011 (Al-Jiburi, 2012). The corresponding geochemical results are presented in Appendix D. Figure 11 depicts EC versus TDS for the 2011 groundwater samples. The plot shows good agreement between the two parameters and also illustrates the differences between the high-TDS groundwater from the shallow wells and the lower-TDS groundwater from the deeper regional wells (Myers, 2012). The two sets of wells have distinctly different ranges of TDS that do not overlap. The geochemical uniqueness indicates that the two zones are not hydraulically connected. Additional figures (Figures 2 through 5) in Appendix E (Myers, 2012) demonstrate further that the groundwater screened by the shallow wells and the groundwater screened by the deeper regional wells are most likely separated by a laterally extensive aquitard.

For comparison purposes, drinking water standards from the U.S. Environmental Protection Agency (EPA) are listed in Table 4 along with the range of values for groundwater samples collected at Al-Tuwaitha in 2002 and 2011. The U.S. EPA has established standards for pH (6.5 to 8.5), TDS (500 mg/L), chloride (250 mg/L), sulfate (250 mg/L), and nitrate (10 mg/L) (U.S. EPA, 2013). Groundwater from both water-bearing zones at Al-Tuwaitha significantly exceeds the U.S. drinking water standards for pH, TDS, chloride (Cl), and sulfate (SO_4). The water quality for both sets of wells is considered to be poor and non-potable. One of the samples from the deeper regional Well 6 had a nitrate concentration of 19 mg/L that exceeded the drinking water standard (Maximum Contaminant Level [MCL]) of 10 mg/L. However, all of the nitrate concentrations for the shallow wells were below the MCL indicating that shallow groundwater is not significantly contaminated with sewage waters (sanitary [septic] waste).

Table 3. Geochemical Results for Groundwater Samples Collected from Al-Tuwaitha Monitoring Wells in 2002

Well	Screened Interval (m, bgs)	Screened groundwater	pH	EC (μmohs/cm)	TDS (ppm)	Ca+ (mg/L)	Mg+ (mg/L)	Na+ (mg/L)	K+ (mg/L)	Cl- (mg/L)	HCO3- (mg/L)	SO4- (mg/L)	NO3- (mg/L)
Well 1	6 - 12	Shallow	7.75	10600	6864	720	626	2050	15	2004	380	1030	0.7
Well 2	6 - 12	Shallow	7.80	13000	8364	680	726	2730	23	2624	448	1092	0.75
Well 5	6 - 12	Shallow	7.70	6960	4492	600	447.7	1173	6.3	1098	344	789	0.4
Well 3	13 - 23	Regional	7.42	4610	2985	160	275.8	1034	4.7	828	144	506.4	0.37
Well 4	12 - 24	Regional	7.35	3040	1977	120	153	695	3.5	583	85	307	0.37
Well 6	24 - 42	Regional	7.30	2820	1830	112	101.6	686	2.6	576	77	252	0.5
8047*	12 – 32	Regional	n.a.	12750	10929	250	561	2800	n.a.	1846	363	5520	n.a.

Note: Analytical data obtained from Abbas *et al*., (2010a). The groundwater sample from off-site well 8047 was probably analyzed by a different laboratory than the samples for Wells 1 - 6. The depth of the screened interval for Well 8047 is not known; the depth shown was inferred from other similar wells cited in Abbas *et al*., (2010a).

bgs = below ground surface
BH = borehole
EC = electrical conductivity (specific conductance)
m = meters
n.a. = not available
ppm = parts per million
TDS = total dissolved solids
TOC = top of casing
μmohs/cm = micromohs per centimeter

Table 4. Comparison of Geochemical Results for Al-Tuwaitha Groundwater Samples and U.S. Drinking Water Standards

Parameter and ion concentrations	Range of 2002 values for Shallow Wells	Range of 2002 and 2011 values for Shallow Wells	Range of 2002 values for Regional Aquifer	Range of 2002 and 2011 values for Regional Aquifer	U.S. Drinking Water Standard (U.S. EPA, 2013)
ph	7.70 – 7.80	5.90 – **9.10**	7.30 – 7.42	6.90 – **8.90**	6.5 – 8.5
EC (μmohs/cm)	6,960 – 13,000	6,185 – 16,150	2,820 – 4,610	1,945 – 6,180	n.s.
TDS (mg/L)	4,492 – 8,364	**4,330 – 11,460**	1,830 – 2,985	**1,040 – 4,326**	500
Ca^+ (mg/L)	600 - 720	144 - 720	112 - 160	20 - 560	n.s.
Mg^+ (mg/L)	448 - 727	107 – 1,013	102 – 276	56 - 488	n.s.
Na^+ (mg/L)	1,173 – 2,730	528 – 2,730	686 – 1,034	196 - 695	n.s.
K^+ (mg/L)	6.3 - 23.0	4.5 - 37	2.6 – 4.7	2.6 - 30	n.s.
Cl^- (mg/L)	1,098 – 2,624	**1,058 – 4,950**	576 - 828	**270 - 990**	250
HCO_3^- (mg/L)	344 - 448	29 - 448	77 - 144	77 - 194	n.s.
SO_4^- (mg/L)	789 – 1,092	**789 – 3,440**	252 – 506	180 – **1,560**	250
NO_3^- (mg/L)	0.4 – 0.75	0.4 – 5.3	0.37 – 0.5	0.37 - **19**	10
Total hardness	--	2,661 – 5,203	--	280 – 3,400	n.s.
Monitoring Well	Well 1, Well 2, and Well 5		Well 3, Well 4, and Well 6		--

Note: Concentrations in **bold** exceed the corresponding drinking water standard.

bgs = below ground surface
BH = borehole
EC = electrical conductivity (specific conductance)
m = meters
mg/L = milligram per liter
n.s. = no standard established by U.S. EPA (2013)
ppm = parts per million
TDS = total dissolved solids
TOC = top of casing
μmohs/cm = micromhos per centimeter

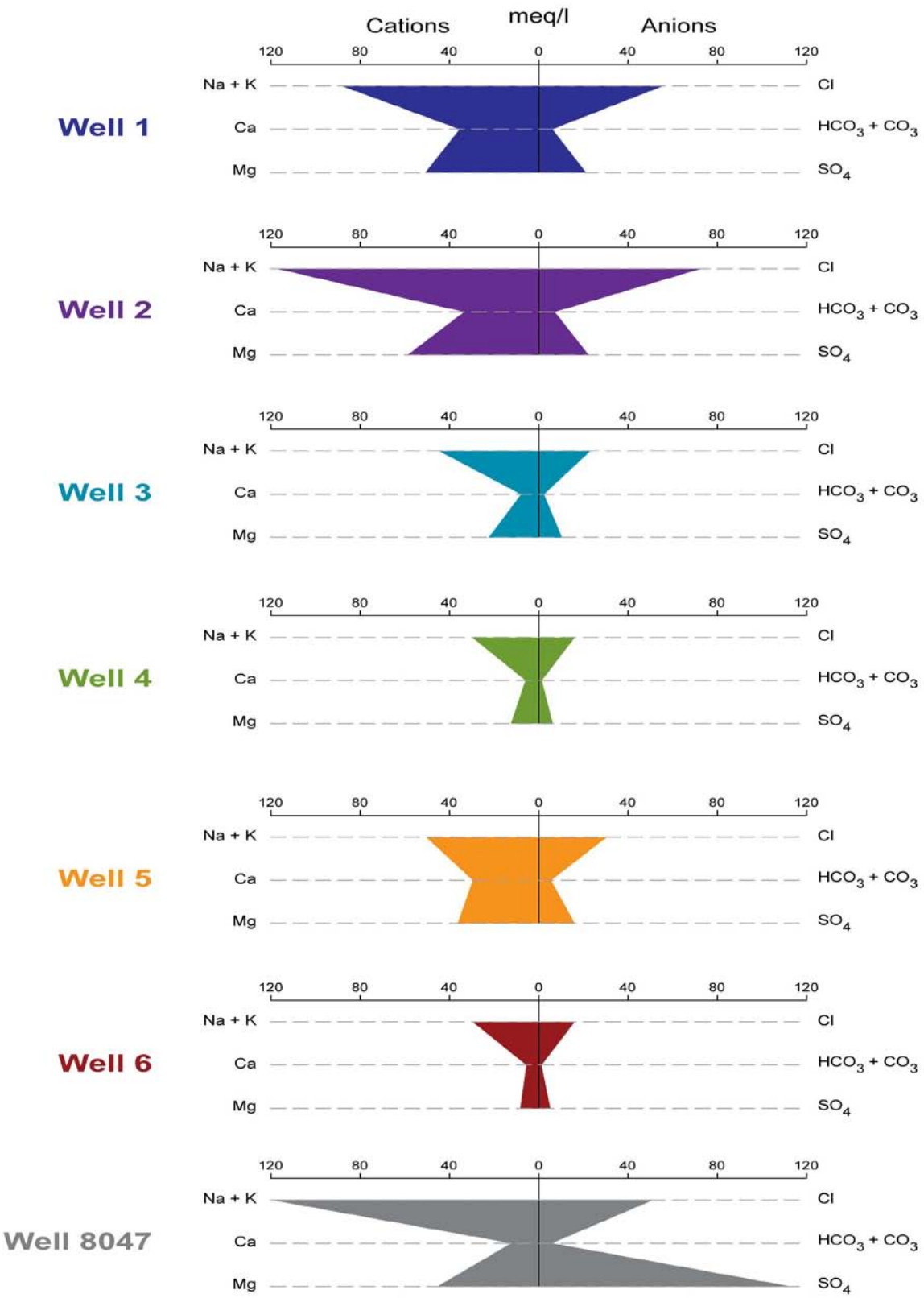

Figure 10. Geochemical Stiff Diagrams for Groundwater Samples Collected in 2002

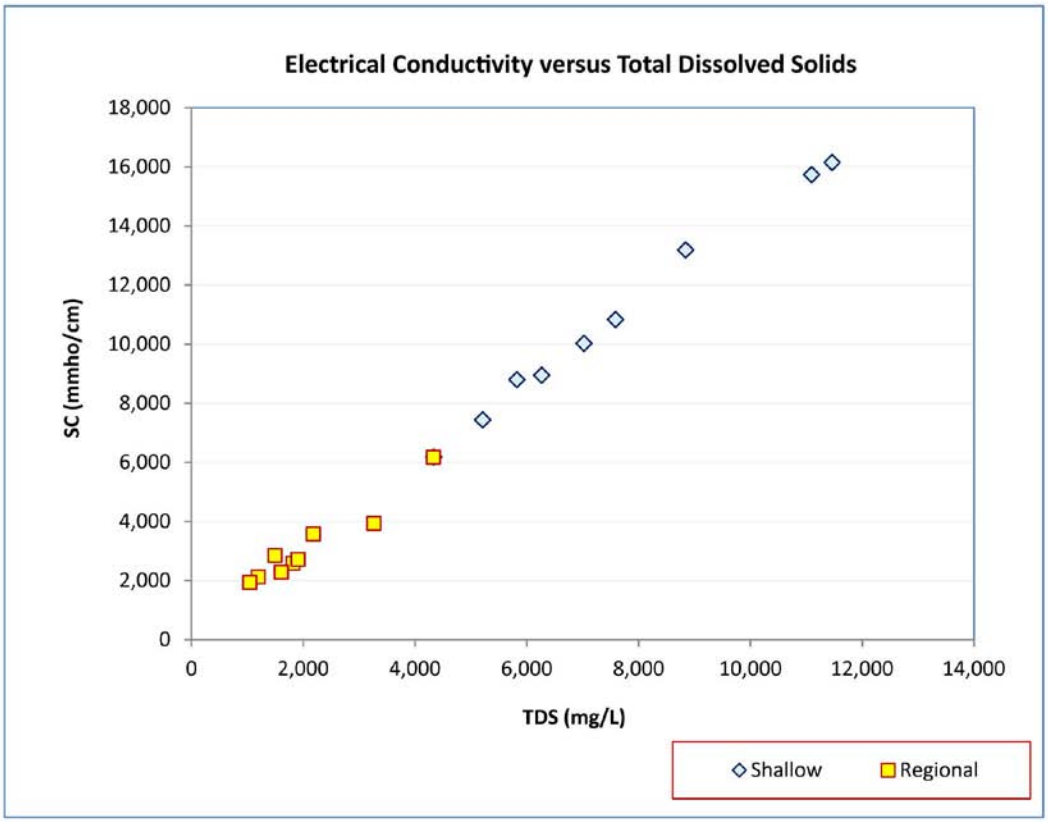

Figure 11. Electrical Conductivity versus Total Dissolved Solids for Groundwater Samples Collected in 2011

Chloride is typically a useful indicator of septic waste, but is most likely not a useful indicator for Al-Tuwaitha because of the saline groundwater. As a result, the possible effects of the septic waste upon groundwater cannot be fully evaluated because no monitoring wells are located in the immediate vicinity of the STP. However, the shallow groundwater zone is not projected to extend as far westward as the STP.

Abbas *et al*., (2010a) made several conclusions regarding the possible effects of facility operation and the Tigris River upon groundwater quality at Al-Tuwaitha. However, the current set of geochemical data is not adequate for making statements other than those discussed above. Additional groundwater sampling and the installation of monitoring wells both inside and outside the berm are needed. The geochemistry of background (naturally occurring) groundwater is not yet well understood.

In addition to the general chemistry parameters, the groundwater samples were analyzed for radionuclides using gamma spectroscopy (Abbas *et al*., 2010a). In 2002, three split samples were collected from each of the six monitoring wells and submitted to the International Radioecology Laboratory (IRL) in Slavutch, Ukraine. For the 2002 samples, all of the radionuclides were below their respective reporting limits except for traces of bismuth-214 and lead-214 in three of the eighteen split samples. The maximum activities for bismuth-214 and lead-214 were 11 and 12 becquerels per liter (Bq/L), respectively. These trace amounts are most likely attributable to naturally occurring background activities or possibly to laboratory artifacts (Abbas *et al*., 2010a). The two isotopes are part of the natural uranium decay series and are likely artifacts in the glass sample bottles (Miller, 2011).

In 2011, groundwater samples were collected from the six monitoring wells in three events (July, November, and December 2011) (Al-Jiburi, 2012). However, specific details of the IRL analytical methodology were not available. Bismuth-214 and lead-214 were not detected (Appendix F). Potassium-40 was detected in groundwater samples collected from all six wells; the maximum activity was 4.2 Bq/L. However, the lack of correlation between the stable potassium and the potassium-40 results (Myers, 2012) indicates that the data quality is insufficient for a conclusion to be made concerning the occurrence of potassium-40 in groundwater. Furthermore, since potassium-40 is a naturally occurring radionuclide, its presence serves only as a functional tracer in environmental sample results (Miller, 2012).

Because specifics of the IRL analytical methodology are not well known, the analytical results for the gamma-emitting radionuclides are considered partially inconclusive. The reporting limits for the radionuclides are unfortunately not known and gross alpha/gross beta analysis are needed for a definitive interpretation to be made. For bismuth-214 and lead-214, the reporting limits are assumed to be 10 Bq/L. If the reporting limits for the other gamma-emitting radionuclides such as cesium-137, cobalt-60, and americium-241 were also 10 Bq/L (equivalent to 270 picocuries per liter [pCi/L]), such detection limits are much too high for evaluating the presence of groundwater contamination. For example, the MCL for radium-226/228 is 5 pCi/L (U.S. EPA, 2013). Additional sampling events with lower reporting limits for specific gamma-emitting radionuclides and additional analytes such as gross alpha/gross beta are needed for assessing the groundwater quality at Al-Tuwaitha. Based on the limited analyses described above, there is no severe contamination of the groundwater at Al Tuwaitha with radioactive constituents.

2.4.7 Data Limitations

The preparation of this GMPP for Al-Tuwaitha is based upon various data limitations. Due to the aerial bombings, looting, and confiscation of records by coalition forces, numerous historical documents are unavailable. Also, the challenging working conditions at the facility have restricted the types of activities conducted to date. The hydrogeologic data and interpretations presented in this GMPP are based upon our current understanding of the facility setting and operations. This understanding is based upon a small dataset of groundwater sampling results and water-level measurements. Additional sampling events with lower reporting limits for gamma-emitting radionuclides and additional analytes such as gross alpha/gross beta are needed. Additionally, there is an insufficient number of wells for a facility that covers approximately 1.2 square km and has at least two water-bearing zones. Multiple rounds of sampling and water-level measurements are typically needed to increase the confidence in hydrogeologic interpretations for a large facility with known soil contamination such as Al-Tuwaitha. As a result, the interpretations discussed earlier in this section should be considered as tentative. Section 5 discusses the types of additional data and information that are needed for firm conclusions to be made about the hydrogeologic regime.

Because topographic maps for the Al-Tuwaitha vicinity and engineering drawings for the facility were not available, satellite imagery from October 2001 through March 2011 was extensively utilized for preparing this GMPP. The ArcGIS website (ESRI, 2011) maintains imagery for 7 October 2001 for the Baghdad area. Historical imagery for seven dates (5 May 2002, 16 July 2002, 5 November 2003, 19 August 2004, 24 June 2009, 18 August 2009, and 12 October 2010) were utilized using Google Earth. A relatively current satellite image (29 March 2011) was purchased from DigitalGlobe Inc.

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3. POTENTIAL SOURCES FOR GROUNDWATER CONTAMINATION

The available historical information indicates that the potential radiological contaminants at Al-Tuwaitha are:

- Cesium-137,
- Cobalt-60,
- Strontium-90,
- Americum-241,
- Plutonium-238,
- Plutonium-239 / Plutonium-240,
- Uranium-235, and
- Uranium-238

3.1 Potential Contaminant Sources at Al-Tuwaitha Facilities

Abbas *et al*., (2010b) identified 18 contaminated buildings and sites at Al-Tuwaitha that were potential sources of radiological contaminants (Table 5). The STP is also listed in Table 5 due to the potential for infiltrating water to impact the water-bearing zones. Because groundwater is shallow at Al-Tuwaitha, these 19 buildings/sites pose a risk for contributing to groundwater contamination. This GMMP assigns a low, medium, or high potential to each of the 19 buildings and sites. The potential was defined as:

- "high" for a building/site that had a waste-storage tank without secondary containment that contained liquid radioactive waste;

- "medium" for a building/site that had a waste-storage tank that contained liquid radioactive waste but was equipped with a secondary containment system; and

- "low" for the remaining sites.

3.2 Potential Sources Upgradient of Al-Tuwaitha

There is also the possibility that upgradient sites have released contaminants that may have migrated to groundwater beneath Al-Tuwaitha. Such contamination might eventually be detected in groundwater samples collected from the on-site monitoring wells. An example of such an upgradient site might be the Ash Shaykili Warehouse Complex located near Al Riyadh. The complex was located approximately 2 km northeast of Al-Tuwaitha and contained about 30 buildings that were used for the storage of nuclear related equipment from Al-Tuwaitha (Global Security.org., 2013). After being looted in 2003, satellite imagery shows that the complex was dismantled sometime between August 2004 and June 2009. Several large excavations contained standing water (possibly sewage) in 2009. These excavations show that some building foundations and the underlying soil were removed. Whether or not this soil was contaminated is not known.

Table 5. Qualitative Assessment of Buildings or Sites with the Potential to Impact Groundwater at Al-Tuwaitha

Building Number	Facility Name	History Related to Potential Groundwater Contamination	Potential to Impact Groundwater
Building 9	Radiochemistry Laboratory	This building contains a storage tank for liquid radioactive wastes. Currently the storage tank contains about 5 m^3 of liquid waste containing high levels of fission products.	High
Building 13	IRT-5000 Research Reactor	Pool-type research reactor used for isotope production. No evidence of leakage from the reactor pool and has been de-fueled. Estimated 55 m^3 of liquid waste plus two tanks outside of the building contain small amounts of radioactive liquid waste.	High
Building 15	Building 15 A – Italian Radioisotope Production Facility	Consists of two hot cells and four below-grade storage tanks containing approximately 1 m^3 of liquid wastes. [Building 15 is partially dismantled.]	Medium
	Building15B – Russian Isotope Production Facility	Contained a number of concrete hot cells, glove boxes, and fume hoods. Liquid wastes were sent initially to an outside tank. Underground liquid transfer system between IRT-5000 Reactor and Building 15B was installed but never used. Currently, liquid waste estimated to be about 35 m^3. Integrity of underground liquid transfer system is unknown. [Building 15 is partially dismantled.]	High
		Four stainless steel tanks (RR1A, RR1B, RR2A, and RR2B) are present on the first floor of Building 15B. All four tanks are assumed to contain 100% solid/sludge waste with no liquids being present. All are connected to underground piping. Two of these tanks were known to contain low level waste.	Low
		Two concrete tanks (RR3 and RR4) are located on the berm outside of the building and are connected to underground piping. Both are assumed to contain 100% solid/sludge waste with no liquids.	High
Building 22	LAMA U Metallurgy	A minor amount of nuclear material was processed. [Building 22 is completely dismantled.]	Low
Building 24	Tammuz-1 and Tammuz-2 Research Reactors	Pool-type research reactor became operational in 1980. Complex system of fluid-transfer channels to two Hot Cells and other pools at other reactor buildings. Possibility of contaminated resins used for cleaning water from water channels and Tammuz-2 reactor pool. A single 3 m^3 stainless-steel tank contains 1 m^3 of liquid waste. [Building is damaged.]	High

Table 5. Qualitative Assessment of Buildings or Sites with the Potential to Impact Groundwater at Al-Tuwaitha (cont.)			
Building Number	**Facility Name**	**History Related to Potential Groundwater Contamination**	**Potential to Impact Groundwater**
Building 35	RWTS	Designed to treat radioactive waste, the RWTS had facilities for compacting and bituminizing radioactive waste. This facility was used to treat liquid waste from the radiochemistry building. The RWTS was damaged, but has been repaired. The storage tanks may be connected to underground piping. Stainless steel tanks (RW1 to RW7) are located on the first floor of Building 35. Most tanks contain or contained medium level waste; but one tank contains waste with high level. Two concrete pits (RW8 and RW9) are both full of liquid.	High
Building 36	Building 36 French Radioactive Storage Silo	Storage of low-level radioactive solid waste, currently in good condition. Few details of the contents are known.	Low
Building 39	RWTS Warehouse for Radioactive Wastes	Warehouse contains solid waste, all contaminated to some extent. No liquid wastes identified but there is bituminized waste and sludge in drums.	Low
	Contaminated Site near Building 39	Mostly radioactive solid wastes, but also has 140 containers containing treated liquid waste contaminated with fission products and actinides. No tanks are located in this building.	Medium
Building 40	Russian Silos	Solid waste is stored in 98 silos (vertical cylinders) above grade. Liquid wastes have evaporated; residue remains. Former liquid waste tank still shows high activity. Contents of the silos and liquid tank are unknown. Existing structure is in disrepair. The surrounding area has scattered contamination. There are unconfirmed rumors of buried contaminated items in the surrounding area.	High
Building 64	Uranium Metal Production	This facility produced approximately 10 kg of UF^4. All equipment was removed, building cleaned, then demolished down to concrete slab. Additional decommissioning work may not be required. Confirmatory radiological surveys maybe needed for the area. [Building 64 is dismantled.]	Low

Table 5. Qualitative Assessment of Buildings or Sites with the Potential to Impact Groundwater at Al-Tuwaitha (cont.)			
Building Number	**Facility Name**	**History Related to Potential Groundwater Contamination**	**Potential to Impact Groundwater**
Buildings 73A and 73B	73A/73B Fuel Fabrication Lab	Facility to purify uranium yellowcake to produce U^3O^8, UO^2, UO^3 and metallic uranium. Structure was heavily damaged. Building 73B Waste Pit (B73.4) consisted of concrete pit and two stainless steel tanks: one contained inactive liquid waste and the other housed liquid uranium-bearing sludge waste. Most of the sludge tank contents removed in 1998. Sub-floor piping contained uranium material. Bottom of the pit contained a thin layer of uranium-contaminated sludge. [Building 73A/73B is dismantled.]	High
Buildings 73C and 73D	C/D Italian Fuel Element Thermal Test Facility	Building 73C was a utilities building; Building 73D was a Fuel Element Thermal Test Facility. Possible scattered surface contamination due to cross contamination from nearby Buildings 73A and 73B. [Buildings 73C and 73C are dismantled.]	Low
Building 85	Technology Hall Uranium Tetrachloride Preparation	UCl^4 development and production; also housed waste recovery activities. Building was leveled and buried by rubble and soil. No surface contamination found in the area. [Building 85 is completely dismantled.]	Low
Building 86	Polonium-210 Production	Designed to extract Po^{210} from bismuth but not known if building was ever used. Currently, building is severely damaged but no contamination is suspected.	Low
None	OUT-1 Burial / Concealment Location, outside berm	Outside the western berm adjacent to the perimeter road, the area may contain up to 100 kg of uranium material. Numerous small containers and vials with concrete boxes are in scattered burials in the adjacent marsh. No liquid was found in containers, which were likely broken when being covered with soil.	Medium
None	Scrap Yards / Burial Sites	Miscellaneous scrap areas and burial sites considered as one unit, consisting of several tonnes of equipment and metal scrap possibly contaminated with uranium. The extent of contamination is not known, but all is suspected to be solid waste.	Low
None	STP (Sewage Treatment Pond)	The STP was used for the disposal of sanitary waste. The water infiltrated into the underlying soil.	High

Note: Historical details are from Dennis *et al*., (2011). Applicable revisions from Chesser (2012) for the historical details are shown in brackets.

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4. CONCEPTUAL SITE MODEL

Figure 12 presents the CSM for Al-Tuwaitha. The model synthesizes the current understanding of the hydrogeologic regime and is useful for evaluating the migration pathways for contaminants with respect to potential receptors. The major components of the model are:

- Topographic relief is low.
- The climate is arid and the precipitation is low.
- Potential evapotranspiration is high.
- Infiltration of rainfall is low. Approximately three percent of the mean annual rainfall is estimated to reach groundwater.
- Surface water runoff is minimal.
- The facility is underlain by a series of unconsolidated alluvial deposits consisting of interfingering layers of clay, silt, silty clay, and fine- to medium-grained sand.
- The vadose zone is comprised of low permeability strata.
- The depth to groundwater varies from approximately 7 to 18 m across the facility.
- Two water-bearing zones, a shallow groundwater zone and a regional aquifer, are present.
- A shallower unconfined (water-table) unit might be as yet unrecognized above the shallow groundwater zone.
- The shallow groundwater zone has the following characteristics:
    - The zone is composed of a layer of silty sand and fine sand that does not extend laterally across the entire facility.
    - The zone is not present in the approximate western part of the facility.
    - The depth to groundwater (the top of saturation) is approximately 7 m bgs.
    - The zone is under semi-confined hydraulic conditions and the potentiometric surface is 4 m bgs.
    - The zone is relatively thin and varies in thickness from approximately 3 to 4 m.
    - The zone is contained within (both overlain and underlain) by an aquitard (low permeability strata).

- The zone potentially has minor, if any, hydraulic communication with the regional aquifer.
- The horizontal gradient of the shallow groundwater zone is low and the inferred groundwater flow direction is generally toward the northwest.
- The zone is potentially recharged by on-site sources including: [1] previous, and possibly ongoing, on-site sanitary-sewer discharges from the STP and possibly undocumented leach fields, [2] waste-water discharges from undocumented leach fields, [3] leakage from damaged waste-storage tanks, [4] landscape irrigation, and [5] a minor amount of infiltration from precipitation.
- The zone has non-potable water quality due to high TDS, chloride, and sulfate concentrations.
- The zone is probably not significantly contaminated with radiological contaminants (based on five sampling events with high detection limits). Non-radiological contaminants such as metals and solvents have not been evaluated.

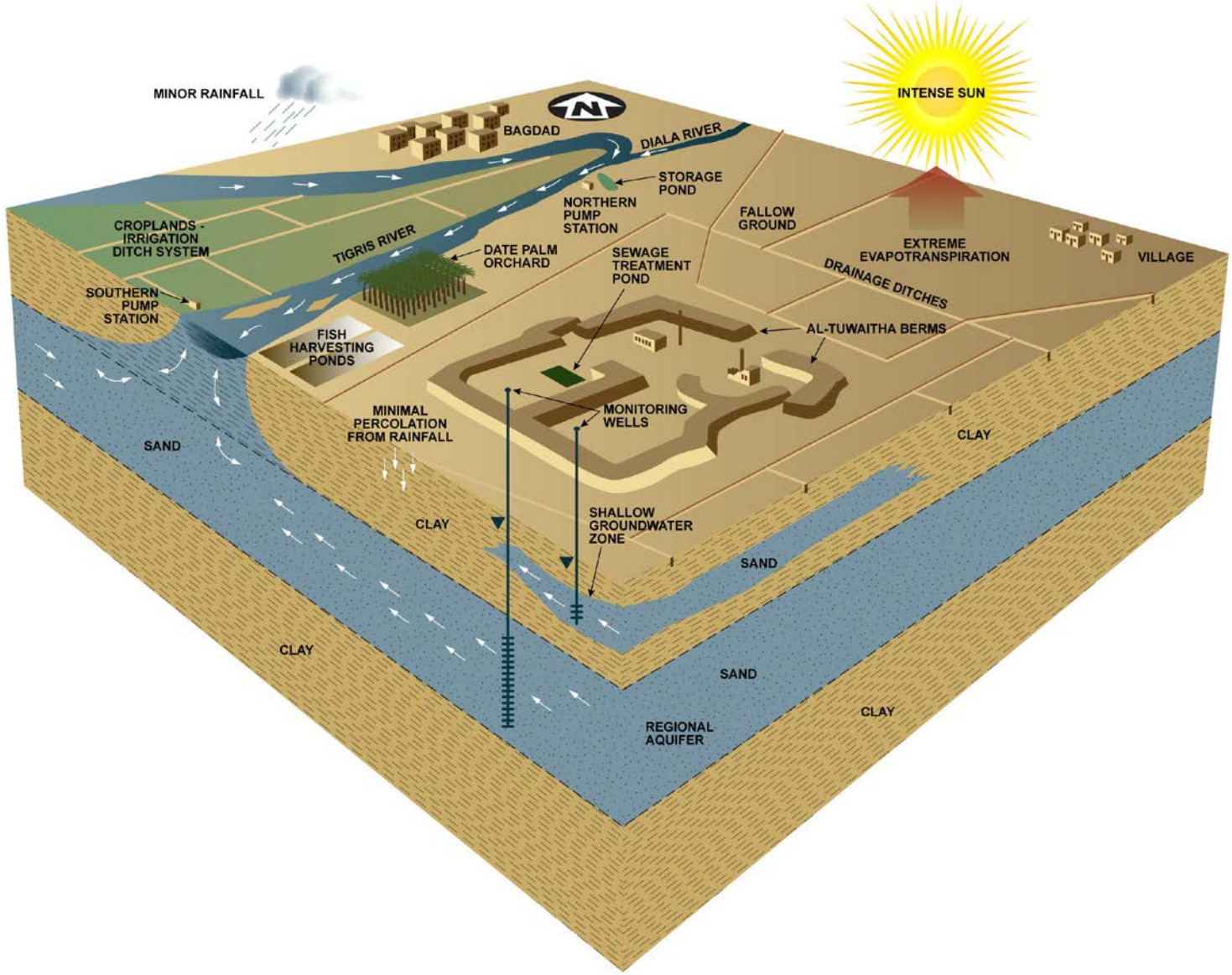

Figure 12. Conceptual Site Model for Al-Tuwaitha

- The regional aquifer has the following characteristics:
    - The regional aquifer is laterally continuous across the facility.
    - The depth to the top of the regional aquifer varies from approximately 14 to 18 m bgs.
    - The regional aquifer is under semi-confined or confined hydraulic conditions and the potentiometric surface is approximately 4 m bgs.
    - The regional aquifer consists of silt and fine-grained sand that coarsens downward to medium-grained sand.
    - The thickness of the regional aquifer is at least 31 m.
    - The regional aquifer is overlain by low permeability clay.
    - The gradient is low and the groundwater flow direction is approximately towards the southwest.
    - Localized recharge sources for the regional aquifer may include the shallow groundwater zone. Recharge sources r probably also include off-site agricultural irrigation and far upgradient natural sources (distant mountainous areas).
    - The regional aquifer may discharge to the Tigris River on a seasonal basis.
    - Groundwater from the regional aquifer is non-potable and has a unique geochemical signature compared to the shallow groundwater zone. The regional aquifer has relatively better water quality (slightly lower TDS, chloride, and sulfate concentrations) than the shallow groundwater zone.
    - The regional aquifer is probably not significantly contaminated with radiological contaminants (based on five sampling events with high detection limits). Non-radiological contaminants such as metals and solvents have not been evaluated.
- Buildings:
    - The buildings at the facility are in various states of condition. Some buildings are significantly damaged while others are in good condition. Some buildings have been removed while others are being dismantled. Some buildings contain uncharacterized solid and/or liquid waste containing radiological contaminants.
    - Waste storage tanks are used for storing liquid and solid wastes that contain radiological contaminants.
    - Basements and underground waste-transfer channels may extend deep enough to intercept the shallow groundwater zone.

- Liquids contaminated with radiological contaminants may have been released from the damaged facilities and from improper waste-handling practices into the subsurface.

- Surface Soil Contamination:
  - Several areas of surface soil contaminated with radionuclides have been confirmed by soil sampling results. The lateral and vertical extents of soil contaminated with radionuclides are not known. Non-radiological contaminants have not been evaluated.

- Potential human receptors of groundwater possibly contaminated with radionuclides are poorly understood and may include:
  - Local residents consuming groundwater.
  - Local residents consuming food grown with irrigation water produced from water-supply wells.

- Ecological receptors of groundwater possibly contaminated with radiological contaminants are poorly defined, but may include:
  - Animals (livestock) that consume surface water after sporadic rainfall or consume groundwater obtained from wells.
  - Animals (livestock) that consume plants and crops that are irrigated using groundwater produced from water-supply wells.

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5. RECOMMENDATIONS AND DATA GAPS

The installation of six monitoring wells in the summer of 2002 represented the initial step in characterizing the hydrogeologic regime at Al-Tuwaitha. Resumption of groundwater sampling and water-level measurements in 2011 advanced the understanding of the hydrogeologic regime. However, additional characterization work is needed for Al-Tuwaitha.

Table 6 lists recommendations for future groundwater characterization activities at Al-Tuwaitha. Previously, Al-Jiburi (2012) presented a list of proposed field activities for Al-Tuwaitha (Appendix G) that was based upon the recommendations presented in Copland and Cochran (2011). The Al-Jiburi (2012) tasks are incorporated into Table 6. Eight monitoring wells are proposed for installation. The anticipated uppermost water-bearing zone at each of the eight proposed wells is also listed in Table 6. The proposed well locations are shown on Figure 13.

Table 6. Recommendations for Future Groundwater Characterization Tasks at Al-Tuwaitha

Recommended Groundwater Characterization Tasks for Al-Tuwaitha
Measure groundwater levels (elevations) on a monthly basis at the six pre-existing monitoring wells.
Measure water levels (elevations) in the Tigris River at one of the pumping stations on a monthly basis.
Resurvey the tops of existing well casings to insure accurate groundwater elevations.
Collect groundwater samples from the six pre-existing monitoring wells on a quarterly basis.
In addition to gamma spectroscopy, the analyte list for groundwater samples should be expanded to include gross alpha/gross beta, volatile organic compounds (VOCs), and heavy metals.
Conduct maintenance and repairs of monitoring wells as needed.
Install eight additional monitoring wells as listed below.
Install four on-site monitoring wells: • Well 7 (regional aquifer) downgradient of the STP • Well 8 (shallow groundwater zone) downgradient of Building 15B • Well 9 (shallow groundwater zone) downgradient of Building 35 • Well 10 (shallow groundwater zone) downgradient of Building 40
Install two off-site monitoring wells north and east of Al-Tuwaitha: • Well 11 (shallow groundwater zone) downgradient of burial location OUT-1 • Well 12 (regional aquifer) between Al-Tuwaitha and Ash Shaykili Warehouse Complex
Install two off-site monitoring wells between Al-Tuwaitha and the Tigris River: • Well 13 (regional aquifer) outside the northern berm to assess influence of the river • Well 14 (regional aquifer) outside the western berm to assess influence of the river
After each proposed monitoring well is installed: • Conduct geophysical logging of the new well • Add the well to the quarterly sampling schedule • Add the well to the monthly water-level measurement schedule

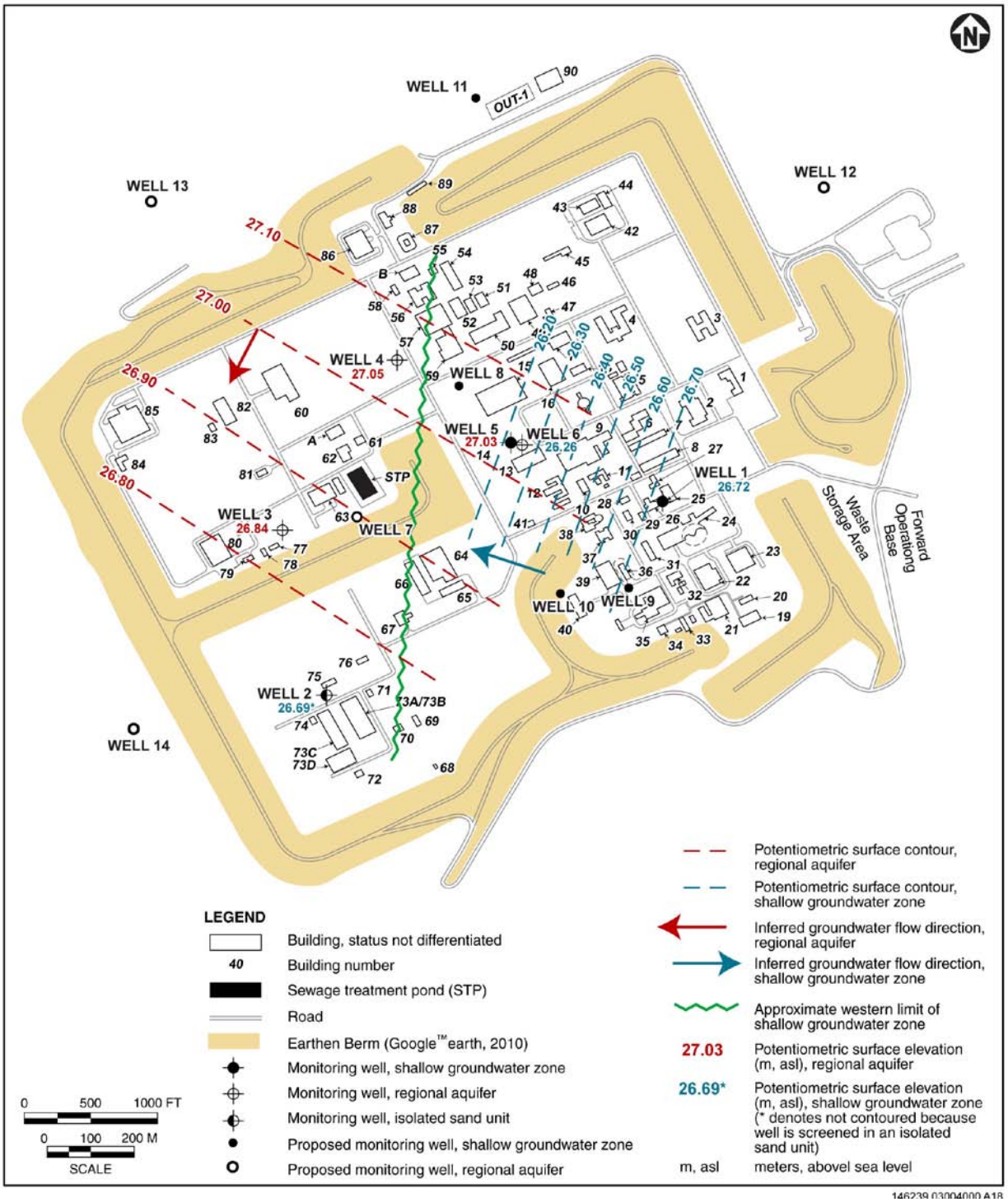

Figure 13. Proposed Monitoring Well Locations for Al-Tuwaitha

A design for the eight proposed monitoring wells is shown in Figure 14 and is based on typical U.S. regulatory guidance. The goal is to construct a monitoring well using the proper drilling technique and the correct well materials so that representative groundwater samples can be collected. The drilling contractor should be knowledgeable and skilled in environmental compliance activities such as the use of environmentally sensitive (nontoxic) materials and the correct decontamination procedures for the drilling equipment. Air rotary or hollow stem augering is the preferred drilling technique for unconsolidated fine-grain sediments. The use of drilling mud should be avoided. Collection of sediment cores would greatly enhance the generation of detailed lithologic descriptions by the field geologist. Nielsen (2006) provides practical guidance for the installation and sampling of monitoring wells and is a useful reference book.

Clean and new materials should be used for constructing the monitoring wells. Polyvinyl chloride (PVC) material is recommended for the well casing and screen due to its inertness and strength. Flush threaded, Schedule 80 PVC with an I.D. of four inches is typically the most useful for the well depths needed at Al-Tuwaitha. A 20-ft (approximately 6 m) long screen is a practical length assuming that the adjacent water-bearing zone has a similar thickness. The use of sand-pack and grout intervals, as shown on Figure 14, will minimize the potential for multiple water-bearing zones, if present, to be inadvertently connected along the well annulus. The slot size of the well screen and the grain size of the sand pack should be selected according to the grain-size distribution of the aquifer material. At Al-Tuwaitha, a slot size of 0.010-inch is probably appropriate for the silty sands. Medium-grained sands probably require a 0.020-inch slot size. Selecting an appropriate grain size of the sand pack with respect to the slot size and aquifer material will minimize the sample turbidity. The sand pack should be composed of clean silica (pure quartz) sand. Bentonite chips and grout should be used to seal the annulus. A locking monument and concrete pad are needed to protect the PVC well casing.

The groundwater samples should be analyzed using gamma spectroscopy (U.S. EPA Method 901.1 or equivalent), and gross alpha/gross beta (U.S. EPA Method 900.0 or equivalent) (Miller, 2011). Both analytical methods should be used for each sampling event. Depending upon the analytical results, subsequent groundwater samples also might need to be analyzed using alpha spectroscopy, beta spectroscopy, and/or mass spectroscopy. A strategy for selecting the proper radionuclide analyses for the groundwater samples is presented in Appendix H.

Although some site-specific data are available as discussed above in the previous sections, more detailed information is required to determine if prior activities and ongoing operations have impacted groundwater. Table 7 identifies the additional information needed to effectively implement this GMPP. Due to the complex and interfingering stratigraphy at Al-Tuwaitha, more than one water-bearing zone may be encountered during the drilling of any particular location. As a result, additional wells may be needed. The installation of additional monitoring and the interpretation of additional hydraulic and contaminant data should be viewed as an iterative approach.

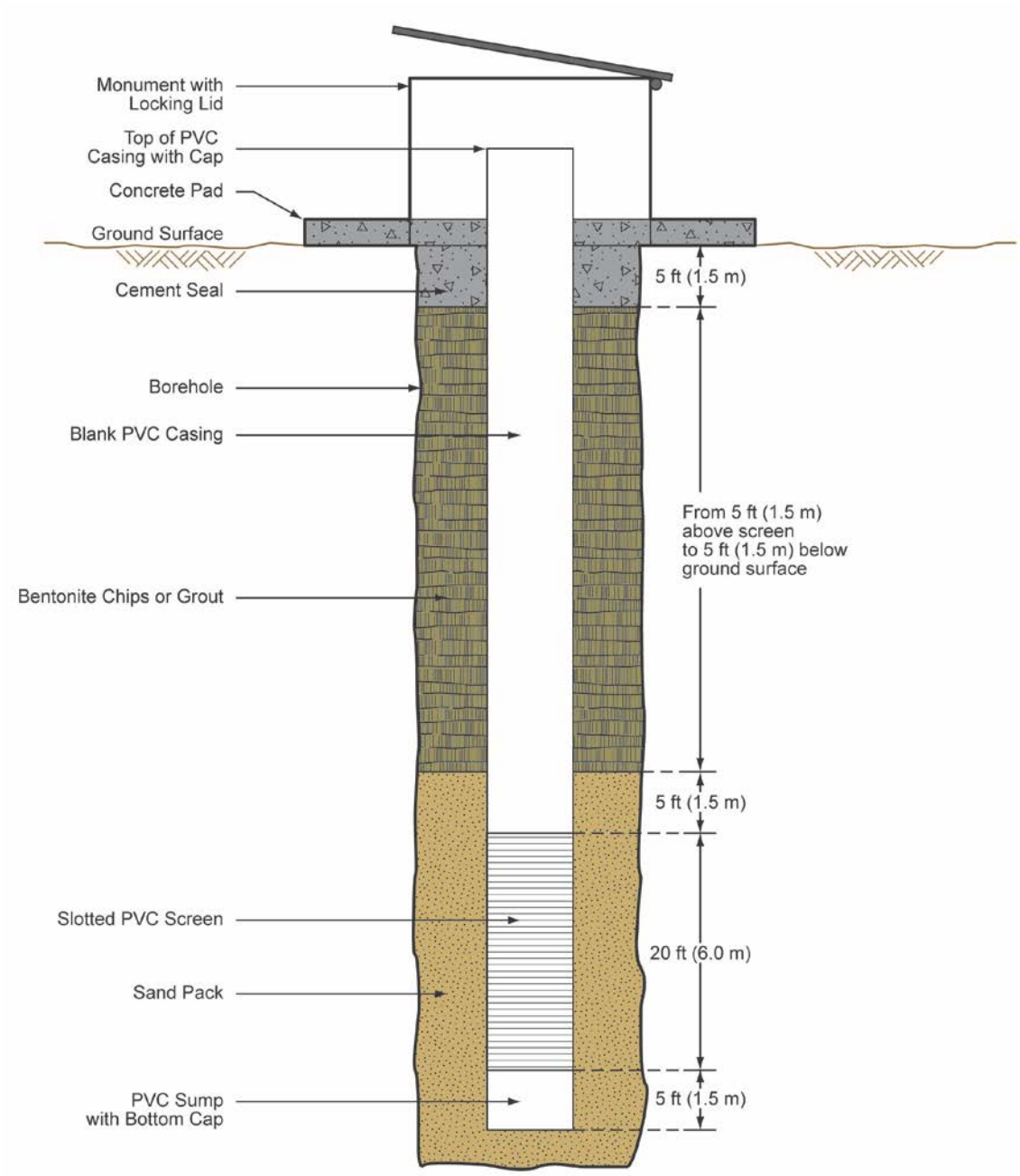

Figure 14. Design for Proposed Monitoring Wells

Table 7. Groundwater Data Gaps for Al-Tuwaitha

Data Gap	Information Needed
Current facility maps and status of activities	Engineering drawings and base maps, current status of buildings, descriptions of ongoing dismantlement and decommissioning work
Hydrogeology	Regular measurements of stage heights (monthly water elevations) of the Tigris River, preferably from one of the nearby pump stations.
	Current source of water for the facility (drinking, irrigation, industrial)
	Status of irrigation canals and drainage ditches surrounding the facility
	More detailed descriptions of site-specific stratigraphy and evaluation of a possible water-table aquifer above the shallow groundwater zone
	Hydraulic parameters for water-bearing zones (conduct slug tests) and vadose zone (laboratory testing of grain size distributions).
	Hydraulic parameters for vadose zone material (laboratory testing)
Groundwater Usage and Protection	Status of off-site groundwater usage (irrigation, agriculture, households, villages)
	Status of on-site groundwater controls (dewatering of building basements, drainage ditches if any,)
	Status of off-site groundwater controls (lowering of groundwater levels for salt control and saline groundwater management)
	Status of on-site water-supply wells, if present
	Presence of off-site wells (hand-dug or drilled water-supply wells)
	Disposition of on-site storm water at Al-Tuwaitha
	Disposition of sanitary sewer discharges (STP and possible leach fields).
Receptors	Confirmation of population and land uses within 5 km of facility
	Presence of sensitive wildlife habitat or endangered species
Potential Contaminant Release Sites	Determine adequacy of monitoring wells with respect to the eight sites with “high” potential risk to groundwater. More monitoring wells will need to be installed at other buildings.
	Upgradient release sites.
Contaminant Distribution	Determine contaminant screening levels for evaluating groundwater samples. Laboratory detection limits need to be less than the screening levels.
	Additional sampling and analyses needed for radionuclides
	Non-radiological contaminants such as metals and solvents (e.g., acetone, trichloroethylene, and methyl ethyl ketone) should be evaluated.

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6. ELEMENTS OF A GROUNDWATER MONITORING AND MANAGEMENT PROGRAM

The elements of a typical GMP are shown on Figure 15, along with the materials and equipment that will be required to successfully implement a GMP for a facility the size and complexity of Al-Tuwaitha. These elements are also discussed below in Sections 6.1 through 6.7.

6.1 Management and Data Analysis Element

As shown in Figure 15, seven work areas are associated with the management and data analysis element. As new data become available, the CSM may need to be revised. Interfacing and meeting with the stakeholders (various government and nongovernment officials as well as concerned citizens) on a routine basis may be necessary. With their input, useful sampling and analysis plans (SAPs) can be prepared. The SAPs will provide critical information for the field crew to use. The creation and ongoing management of effective training processes (administrative, safety, and equipment operation) is a critical task. For implementing management tasks, the use of formalized operating procedures (OPs) and administrative operating procedures (AOPs is beneficial. For some field tasks such as installing monitoring wells, contractual items such as bid packages, statements of work and contracts will need to be coordinated with outside contractors. Conducting the field tasks will require adherence to various field operating procedures (FOPs). Examples of applicable SNL procedures are listed in Appendix I. EPA (2001) discusses the development of a Quality Assurance Project Plan (QAPP) in support of sampling programs. A QAPP integrates all technical and quality aspects of a project including planning, implementation, and assessment.

A training system focused on safely performing the field work is important. The dual goals of working safely while accomplishing field tasks on schedule will be challenging for a logistically complex facility such as Al-Tuwaitha. To that end, the training of personnel should be a continuous process. Technical staff members are generally qualified to perform program functions by education and experience, supplemented with training. Field technicians may or may not have specific related experience prior to joining the field crew. Personnel shall receive all available required training within a few months of initial hire and shall update their training on a periodic basis. Training records should be documented and kept in a training education database.

The principal materials and equipment for implementing the management element are office space and storage space. Office space to accommodate five to ten staff members is needed. The office space should have office equipment such as desks, computers, copy machine, and file cabinets. A building or garage to store the field equipment is desirable. The storage building or garage should have work benches. Numerous tools for performing maintenance on the sampling equipment are needed. Storage is also needed for expendable supplies (e.g., sample containers and some personnel protective equipment [PPE]), tools, and sampling equipment. A dedicated desk and work bench to serve as a sample management point is helpful for packaging and documenting the samples for shipment to analytical laboratories. A records center (desk and file cabinets) for storing documents such as sampling data, field forms, maps, photographs, and analytical reports is recommended.

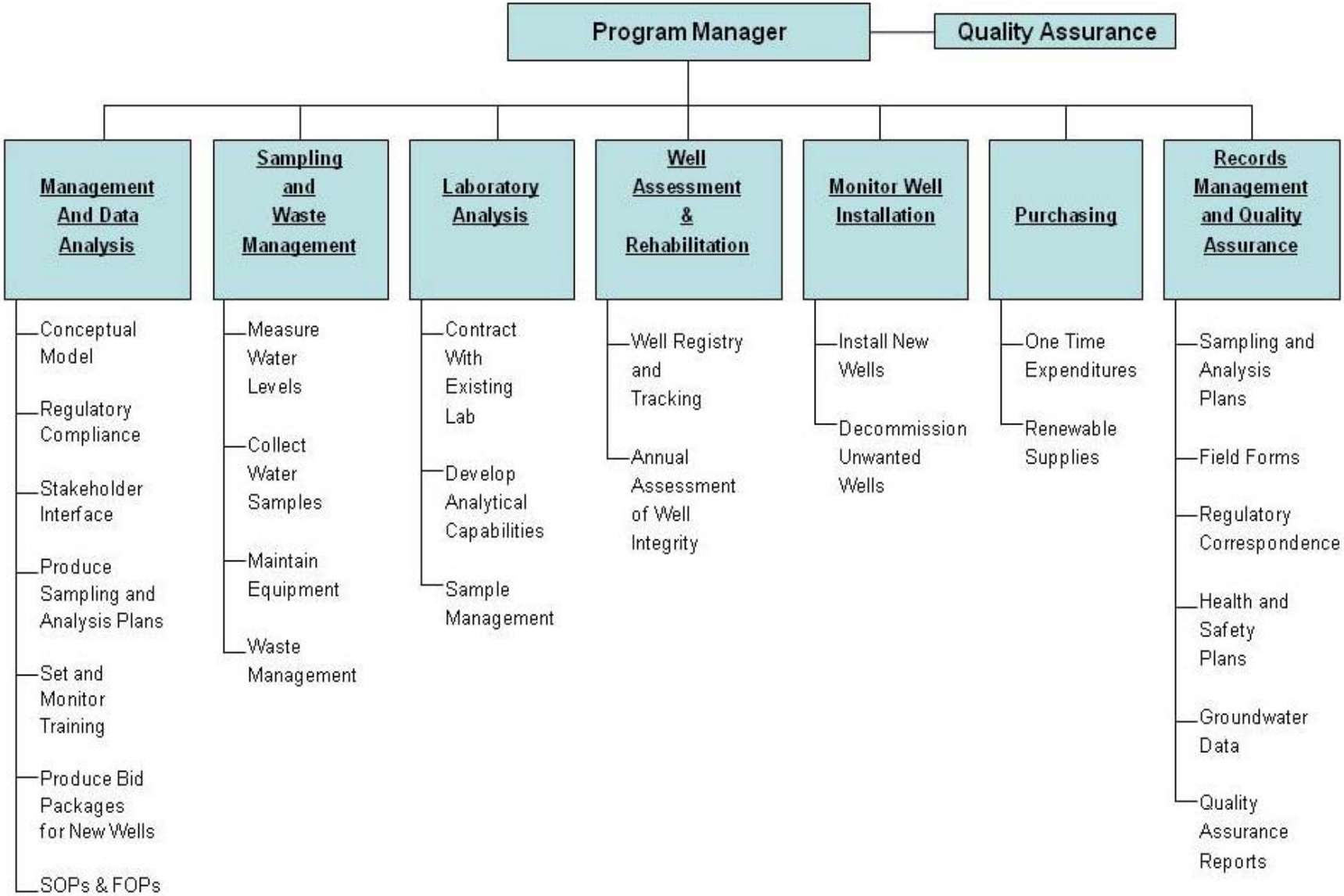

Figure 15. Major Organizational Elements of a Groundwater Monitoring Program.

For implementing this GMPP, contracts will need to be set up with outside contractors such as:

- drilling company for installing monitoring wells,
- geophysical logging company for surveying new wells,
- analytical laboratory(s) for groundwater samples, and
- possibly an independent data-validation contractor.

6.2. Sampling and Waste Management Element

As shown in Figure 15, four work areas are associated with the sampling and waste management element. Field efforts are required to measure water levels and to collect groundwater samples from the monitoring wells. The water-level data are important for establishing the groundwater flow direction and gradient for each water-bearing zone, and for identifying possible changes in flow direction and velocity. Water elevation data are also needed for the Tigris River, preferably from a nearby location such as one of the pump stations.

Sample collection procedures should take into consideration the specific construction details and water level for each monitoring well. The use of proper sample collection technique will allow for the collection of representative groundwater samples. Ideally, the monitoring wells should be sampled using a portable Bennett™ submersible pump system or equivalent. Field instruments will be used to measure the groundwater parameters (temperature, pH, electrical conductivity, oxidation reduction potential, dissolved oxygen, turbidity, and water levels).

Calibration and periodic maintenance of the measurement and sampling equipment is important, especially because of the saline groundwater. Thorough decontamination of the equipment can mitigate the corrosive effect of the saline groundwater. Proper tracking and disposal of investigation derived waste, such as purged groundwater, are an integral part of the waste management process.

A vehicle (van, truck, or trailer) that is dedicated to the sampling effort can expedite the field effort and increase the consistency of the process. The vehicle is useful for transporting the field crew, equipment, and sample containers as well as keeping the process organized and equipment clean. Hand tools and power tools will occasionally be used to repair the well heads. Unique tools and expendable supplies are necessary too for calibrating and maintaining the sampling equipment.

6.3. Laboratory Analysis Element

As shown in Figure 15, three topics are associated with the laboratory analysis element. The objective of groundwater sampling is to provide defensible analytical data that can be used to evaluate groundwater quality. Significant statistical deviations from the trends will be evaluated to determine if groundwater contamination is, or has, occurred. Understanding the naturally occurring (background) distribution of geochemical and radiological results is critical.

Integral in creating and maintaining an effective business contract with an analytical laboratory is the need to utilize site-specific quality assurance (QA) and quality control (QC) requirements and goals that are specified in the QAPP. Initially, an off-site analytical laboratory could be

used. As the GMP matures at Al-Tuwaitha, the development of an in-country, preferably an on-site analytical laboratory would be beneficial. Off-site analyses would occasionally be necessary for validating the on-site laboratory results by analyzing duplicate sets of groundwater samples. The sample management point mentioned above could be dedicated to managing various processes such as field logistics, tracking sample containers, packing sample coolers, preparing chain-of-custody forms, documenting shipping manifests, and conducting QC checks. In large GMPs, sample management is a full-time job for at least one person.

The materials and equipment needed to implement this element are the office-space items discussed above in Section 6.1.

6.4. Well Assessment and Rehabilitation Element

As shown in Figure 15, this element combines the Well Registry and Tracking task with the Annual Assessment of Well Integrity task. The Well Registry and Tracking process provides for ongoing oversight of the monitoring wells and provides a management mechanism for corrective actions. Options for corrective action include maintenance and repair to bring the monitoring well into conformity with groundwater protection standards. The Well Registry is a central database that records information concerning the monitoring well location, construction details, installation technique, and operational history.

An annual assessment of well integrity involves the inspection of each monitoring well to verify good working condition and security. The depth to water and the total depth of the well should be measured and compared to previous measurements. Items to inspect are the protective casing, pad lock, vented cap, guard posts (bollards), and the cement pad. If the well has been damaged from a vehicle collision or the ground surface has subsided, a thorough inspection is needed to determine if surface water or soil can inadvertently enter the well casing or annulus. Minimizing the potential for groundwater contamination is vital. Corrective actions will need to be completed as soon as possible. A review of the sampling data is also important. If the well is yielding less water and the drawdown is increasing during sampling events, the well screen may need to be redeveloped by bailing, surging, and/or air lifting. The fine-grained sediments provide a source of material that can readily “silt up” a well screen. By tagging (measuring) the total depth of the well on a regular basis, the amount of silt that accumulates in the well bottom can be assessed. The presence of accumulated silt can be indicative of silt/clay partially plugging the well screen. An accumulation of approximately 0.5 m or more of silt can indicate that the well should be redeveloped. Well yield might also be adversely affected by bio-fouling (the growth of bacteria). Furthermore, the data from the well inspections and maintenance needs to be recorded in the Well Registry database.

On a less frequent basis, a downhole video camera may be used to examine the interior of the well casing and screen. Defects due to corrosion or a cracked casing/screen can increase the silting potential and may also create a pathway for inadvertent groundwater contamination. In the event the well cannot be restored to the required standards, or the well is no longer needed for data collection, the well may need to be properly decommissioned (plugged and abandoned).

Wells that become damaged or are determined to have been poorly constructed (such as with an ineffective annular seal that allows surface water to enter the well casing or allows groundwater

to flow between different water-bearing zones) should be plugged and abandoned using the proper technique. Steel well casing and screen can be left in place and the interior should be grouted to the surface using bentonite grout slurry. The upper 2 m of the casing should be filled with cement. PVC casing should be over-drilled and the borehole filled with grout. Existing well pads, protective steel casing, and guard posts should be removed and the well casing cut off at least 0.5 m bgs. A concrete pad should be constructed with a brass marker containing the well name and the date of abandonment. The details should be documented in the Well Registry. If a replacement well is needed to satisfy an ongoing characterization or monitoring need, the new well should be installed at least 3 m distant from the original well.

At a minimum, the materials and equipment needed to implement this element are: a water level meter for measuring the depth to water and the total depth of the well casing, a pair of radiation survey meters (beta/gamma detector [Geiger-Mueller Probe] and a microR meter or RO-20 ion-chamber meter) for evaluating the work area surrounding the well and the outside of each sample container, and a photoionization detector (PID) for determining if VOCs such a trichloroethylene or acetone are present in the well casing or in ambient air (the surrounding work area). A downhole video camera attached to a cable reel can be a useful tool for determining the integrity of well casing if the groundwater is not too cloudy (obscured by suspended silt and clay).

6.5 Monitoring Well Installation Element

To conduct the recommended tasks discussed earlier in Table 6 and address the data gaps outlined in Table 7, additional monitoring wells will need to be installed at Al-Tuwaitha. The number and depths of additional wells should be based up the findings obtained during the annual well inspection and additional measurement/sampling events of the existing wells. For the new wells, the well casing and screens should be constructed of PVC which is resistant to the corrosive effects of saline groundwater (Nielsen, 2006). Portable sampling pumps should be used at Al-Tuwaitha. Installing dedicated pumps in each well would most likely not be cost effective because the saline groundwater is highly corrosive to metal components.

The materials and equipment needed to install and develop a new monitoring well are typically supplied by a drilling contractor. The materials include well screens, well casing, bottom cap, centralizers, sand pack, bentonite grout, cement, casing cap, protective monument (stovepipe), and pad locks. Clean, new materials should be used for constructing each well. The materials should be factory sealed in plastic (polyethylene) bags. Drilling equipment needs to be decontaminated for each well location. Downhole geophysical logging should be conducted after each well is installed. Each well must be developed using bailing, surging, and/or pumping.

6.6. Purchasing Element

A GMP must have the infrastructure (or access to the infrastructure) to purchase one-time items and renewable supplies. This could include “off-the-shelf” purchases and the awarding of contracts for drilling and analytical work.

The one-time expenditures consist of long-life items such as the sampling pumps, water-level meter, PID, radiation meters, and a digital camera. The renewable supplies consist of items such as gloves, decontamination detergent, PPE, labels, and wrapping tape. Table 8 lists both types of elements.

Table 8. Recommended Groundwater Sampling Equipment

One-time and Renewable Items	Description
Sample Pump	Model 1800, Bennett Sample Pump Inc.
Power Drive Reel	Model R2PD-60, Bennett Sample Pump Inc.
Tube Bundle	RPTLF3-6 Tube Bundle (polypropylene)
Tape	PVC Tape Wrap
Water Quality Meter	YSI 6920 V2 sonde, YSI Inc.
Data Logging System	YSI 650MDS data display and logger
Flow Cell	YSI 5803
pH Standards	Reference values for 4.00, 7.00, 10.0 pH units
EC Standards	Reference value : 1278 µmhos/cm at 20˚C
ORP Standards	Reference value : 200 milliVolts
Turbidity Meter	HACH 2100 Turbidity Meter, HACH Company
Turbidity Standards	Gelex Standard Kit, HACH Company
Water Level Meter	Solinst Model 101, Solinst Canada Ltd.
PID	RAE Systems MiniRAE 3000 or equivalent, RAE Systems Inc.
Electrical Power Generator	120 Volt, 60 Hertz, for powering the sample-pump reel
Pressure Regulators	Swagelok® manufacturer
High Pressure Hoses	Sampling system component
Nitrogen Gas cylinders	For operating the sampling pumps
Tube fittings, valves	Swagelok® manufacturer
Teflon and Nylon Tubing	Sampling system component
Stainless Steel Tubing	Sampling system component
Tool Box / Tools	Assorted wrenches, screwdrivers, pliers, c-clamps, socket set with ratchet, tie-down straps, zip-ties, duct tape
55-gallon drums	Polyethylene drums for storing purge water
Deionized Water	Water for preparing sample blanks and cleaning equipment
Detergent	Alconox brand
PPE	Coveralls, nitrile gloves, safety glasses, steel-toe boots, hard hats
First Aid kit	For minor injuries

6.7. Records Management and Quality Assurance Element

Records consist of the various types of documents, reports, correspondence, photographs, maps, figures, and computer files. All relevant records need to be stored and maintained for immediate and long-term use. The records can consist of either hard copy (paper) or digital media (computer files, etc.).

A process for documenting regulatory correspondence needs to be implemented. For example, a system should be used for tracking the submittal of documents to the regulators and subsequently acknowledging responses to their queries. Each document should have a descriptive cover page that summarizes the category of the subject matter so that the document can be more easily identified and retrieved from the record files.

Groundwater related documents such as drilling logs, well-construction diagrams, and sampling forms need to be stored and maintained in a permanent archive. The QA documents including data validation reports need to be maintained as well. The documents need to be indexed and readily accessible to facility workers. The supporting data should be stored as hard-copy forms and integrated into a database management system so that it is available electronically to all users. Interpretation of water-level measurements and the analytical data should be summarized in groundwater monitoring reports that are submitted to the appropriate government agencies.

MoEN should be an active participant in environmental education and outreach programs throughout the adjacent communities and villages. Open access data and information could be maintained on-site, in a nearby library, and/or at a national archive/data repository. Public meetings with poster presentations could enhance communication and understanding of the groundwater issues. The public could also participate in the decision-making processes for protecting groundwater quality. Public participation typically enhances credibility for facility workers and contributes to an understanding of environmental stewardship. Public outreach can also include presentations to schools, special events, and environmental conferences. These venues can promote productive communication between the professional community, the public, and various management levels in the government.

Information should be available in a variety of formats including: maps, reports, data tables, fact sheets, graphics, and videos. Low-tech information technologies, such as paper copies are the most prevalent and perhaps longest lasting record. To reach a larger portion of the public, high-tech information technologies should also be considered including internet access webportals and the distribution of compact discs.

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7. PROGRAM MANAGEMENT AND KEY PERSONNEL

This section describes the key personnel required to successfully perform the GMP tasks and the general duties required of each of the positions listed.

7.1 Program Manager

The Program Manager (PM) for the GMP is responsible for the administration of the GMP and for the coordination with other facility-wide programs such as building decommissioning and dismantlement. The PM not only manages the GMP and staff, but also sets the priorities, secures funding, and interfaces with other agencies.

7.2 Task Leader

The Task Leader (TL) reports directly to the PM. The TL is the lead scientist on the project and is the principal investigator with the most technical knowledge of groundwater conditions at the facility. The TL interacts with experts in the disciplines of hydrogeology, chemistry, and health physics; sets up contracts with drilling, laboratory, and other contractors; and performs and/or oversees the data review and report writing.

The TL oversees water-level measurements that should be collected from monitoring wells on a routine schedule. Such data are important for determining groundwater flow directions and gradients. The TL also oversees groundwater monitoring activities that include periodic sampling of the monitoring wells. The analytical data for the groundwater samples will be used to allow for the early detection of groundwater contamination and provide background water quality concentrations. The groundwater monitoring process also includes data validation, data reduction, data analysis, and interpretation of the water quality data. The data should be entered into the appropriate database management system so that it is available electronically to users. The monitoring data should be used to evaluate water quality trends. Significant deviations from these trends will be analyzed to determine if groundwater contamination is present. The results of the water quality and water-level data should be documented in periodic reports such as quarterly and annual groundwater monitoring reports.

If a comprehensive Health and Safety Plan (HASP) is not available for the Al-Tuwaitha facility, such a HASP should be prepared. The HASP should discuss field tasks, potential hazards, personnel responsibilities, personnel contact information (phone numbers, etc.), radiological and chemical exposure pathways, heat-stress mitigation, biological hazards (insects, etc.), emergency procedures, and a map to the nearest hospital or egress location.

7.3 Sampling Coordinator

The Sampling Coordinator (SC) is an essential individual in any GMP. Before the next sampling event is conducted at Al-Tuwaitha, the SC should write a comprehensive SAP. The goal of an SAP is to ensure that valid and reliable groundwater data are collected to determine if past or current operations have impacted groundwater. The selection of useful data quality objectives (DQOs) is essential. The DQO process is explained in EPA (2000). Also, QA procedures should be used to determine if the DQOs have been attained and if the data are suitable for their

intended use. For example, the recording of groundwater parameters during sampling should attain the data quality goals as specified in the relevant FOP. Also, laboratory analyses must also comply with industry standard procedures and protocols. Specific conditions of accuracy, precision, representativeness, completeness, and comparability should be imposed on the analytical data to validate the usefulness of the data for interpretative purposes. The data validation process also involves the review of holding times, duplicates, and split samples. An independent contractor who is not associated with the facility, the analytical laboratory, or any government agency may be needed to conduct a thorough data validation.

7.4 Groundwater Sampling Field Crew Leader

The Groundwater Sampling Field Crew Leader (FCL) reports directly to the TL, and is the lead field technician with the most technical knowledge of groundwater sampling equipment and procedures. The FCL is in charge of sample management and health and safety of site workers. This position is the primary lead of the GMP field work and is responsible for determining the equipment requirements and producing the documentation required to perform work in the field. The duties include:

- Maintaining a working knowledge of monitoring well construction details.
- Maintaining a working knowledge of water chemistry, of the methods used to measure these parameters, and of the equipment and calibration methods used to collect this data.
- Maintaining familiarity of all aspects of the GMP from the collection of groundwater samples, analytical methods, packaging and labeling requirements, and delivery process to analytical laboratories, decontamination and waste management procedures.
- Updating operating procedures and other related technical documents.

7.5 Groundwater Sampling Field Crew

The Groundwater Sampling Field Crew is a group of two to three technicians that directly report to the FCL. The Field Crew consists of environmental field technicians that primarily measure water levels and collect groundwater samples, but can also provide additional support for other environmental programs at the facility. Field crew members should have a diverse and practical knowledge of groundwater sampling procedures, strong mechanical and electrical skills, and be health and safety trained.

Operations performed by the field crew include groundwater level measurement, equipment decontamination, instrument calibration, well purging, sample collection, and sample shipment. The crew members conduct routine maintenance and inventory all equipment and supplies necessary to perform day to day operations.

On a daily basis, field crew members will be responsible for determining the equipment requirements, installation needs, and troubleshooting of the groundwater sampling system. The use of a truck- or trailer-mounted system is helpful. Members need to have an ability to adapt to new working requirements as they maintain familiarity of all aspects of the GMP ranging from the collection of groundwater samples, to the characterization of samples, the packaging and

labeling requirements, conducting sample management (tracking and delivery of samples to analytical laboratories), decontamination of sampling equipment, and implementing waste management procedures.

Field activities should be documented in a logbook and on field forms. Types of information to be documented while collecting groundwater samples include:

- name of the sampling activity
- identities and responsibilities of the sampling crew members
- date and time of the sampling activity
- sampling location (well number)
- weather conditions
- well data – depth to water, total well depth, sampling depth
- purge data – volume of groundwater removed prior to sampling
- values of water stability parameters at the completion of well purging
- sampling device (pump, bailer, etc.) model and serial numbers
- sample description (qualitative) – as appropriate: color, odor, turbidity
- sample numbers and chain of custody numbers
- general field observations including any equipment malfunctions
- deviations (variances) from SAPs and other sampling protocols, and
- documentation of safety issues.

7.6 Records Manager

The Records Manager has responsibility for acquiring and preserving documents so that staff and outside individuals can access the documents in a timely manner. The responsibilities include:

- Maintaining a tracking system,

- insuring that relevant documents, field forms, correspondence, etc. are submitted to a new Al-Tuwaitha environmental Records Center,

- storing hard and digital copies in a secure and permanent archive, and

- documenting the distribution of documents to various individual and groups.

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8. CONCLUSIONS

This report develops a GMMP and CSM for the RPC. Groundwater data collected from six on-site monitoring wells, several years of satellite imagery, and various reference materials obtained from government of Iraq staff and from Internet searches were used to develop the CSM. In summary, two water-bearing zones (a shallow groundwater zone and a regional aquifer) were identified at Al-Tuwaitha. The depth to the shallow groundwater zone varies from approximately 7 to 9 m where present in the eastern part of the facility. Because the shallow groundwater zone is semi-confined, groundwater does have the potential to rise upwards in a well or trench to depths as shallow as 4 m, which is the potentiometric surface. Neither the shallow groundwater zone nor the regional aquifer is a source of potable water due to the naturally occurring high salinity common to the Mesopotamian Plain. Based upon the limited analyses described in this report, there is no severe contamination of the groundwater at Al-Tuwaitha with radioactive constituents. The potential presence of non-radiological contaminants has not been evaluated. The relationships of on-site features such as monitoring wells, buildings, and radioactive waste storage tanks to that of off-site features such as agricultural fields, villages, and the Tigris River are described. The primary exposure pathways for contaminated groundwater to impact human health are through off-site water-supply wells and the irrigation of crops.

Eight of nineteen buildings and sites at Al-Tuwaitha were assigned a “high” risk factor as potential sources of groundwater contamination. In addition to the need to characterize these high risk sites, a number of other data gaps were identified, including: the need for the installation of more monitoring wells, the collection of groundwater samples for radiological and chemical analyses, and the need to further characterize the various storage tank systems and associated underground piping. Updated information on the waste storage areas is needed, as is monthly information on the water levels in the monitoring wells and the Tigris River. Groundwater samples should be collected on a quarterly basis. In addition to gamma spectroscopy and geochemical parameters, the analyte list should be expanded to include gross alpha/gross beta, VOCs, and heavy metals.

The proposed locations for eight additional monitoring wells were specified in this GMMP. Wells were proposed for both on-site and off-site locations. To fully characterize the facility and vicinity, an additional 10 plus monitoring wells might be needed. The installation of monitoring wells will be an iterative process and might involve several campaigns of drilling activity. The knowledge gained from each drilling campaign and subsequent measurement and sampling events should be used to guide subsequent work.

This report (and specifically Figure 15) describes the organizational elements of a typical GMP along with the required staff and equipment needs. A practical and thorough understanding of the hydrogeologic regime of Al-Tuwaitha can be obtained by implementing this plan. Also, any potential groundwater contamination can be evaluated with respect to protecting human health and mitigating potential impacts to the environment.

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9. GLOSSARY OF HYDROGEOLOGIC TERMINOLOGY

Aquiclude. A stratigraphic unit with very low hydraulic conductivity such as a continuous layer of clay that completely limits the vertical migration of groundwater.

Aquifer. A stratigraphic unit capable of yielding groundwater to a well or spring.

Aquitard. A stratigraphic unit with low hydraulic conductivity that partially limits the vertical movement of groundwater.

Characterization. The collection of hydrogeologic data collection and chemical analyses in order to that define the groundwater setting and contaminant distributions. For example, to reduce uncertainty about the rate and direction of groundwater flow, data are needed for groundwater level, hydraulic conductivity, and hydraulic gradient for each stratigraphic unit.

Confined Aquifer. An aquifer that is overlain by low permeable materials such as an aquiclude. A confined aquifer typically has a potentiometric surface that is higher in elevation that the upper surface of the aquifer material.

Gaining Stream. Groundwater discharges from the aquifer to the river or stream. Also known as an effluent stream.

Groundwater. Typically refers to the water contained within a saturated soil, sediment, or bedrock. (Soil moisture in the vadose zone [above the water table] is not considered to be groundwater.)

Hydraulic Conductivity. The capacity of a stratigraphic unit to transmit water.

Hydraulic Gradient. Change in head per unit of distance measured parallel to the groundwater flow direction.

Losing Stream. Surface water from the river or stream flows into and thereby recharges the aquifer. Also known as an influent stream.

Off-site. An object or feature located outside the Al-Tuwaitha berm.

On-site. An object or feature located inside the Al-Tuwaitha berm.

Perched aquifer. An aquifer underlain by low permeable material that overlies a more extensive aquifer. A perched aquifer generally refers to a small localized aquifer that occurs at an elevation higher than the deeper regionally extensive aquifer. Both the lateral extent and thickness of a perched aquifer is typically much less than a regional aquifer.

Potable. Water suitable for drinking purposes without the need for additional treatment or filtration. Commonly known as drinking water.

Quaternary. The Quaternary Period is comprised of the last two geologic epochs: the Pleistocene and the Holocene. This Period is defined as occurring from 2.6 million years ago to the present.

Potentiometric Surface. An interpretive surface that represents the total head in an aquifer. The elevation to which water will rise in a well due to combined effect of elevation head, pressure head, and gradient head.

Quality Assurance. Systematic monitoring and evaluation of the various aspects of a product, service, or project to maximize the probability that standards of quality are being attained. Based upon two principles: the product should be suitable for the intended purpose and mistakes should be eliminated and not repeated in subsequent work. Quality assurance attempts to improve the process in order to minimize issues that lead to substandard results in the first place.

Quality Control. Process for evaluating the quality of factors involved in the producing a work product. Emphasis is applied to three primary aspects: (1) job management process, (2) competency of personnel (knowledge, skills, experience, training, qualifications), and (3) personnel behavior (integrity, confidence, organization culture, motivation, relationships). Quality control emphasizes the testing and reviewing of products and reporting the results to management so that improvements can be implemented.

Regional Aquifer. An aquifer that extends laterally across a significant geographic area.

Semi-confined Aquifer. An aquifer that is overlain by low permeable materials such as an aquitard. A semi-confined aquifer typically has a potentiometric surface that is higher in elevation that the upper surface of the aquifer material. An aquifer test (slug or pumping) is typically needed to differentiate between a confined and semi-confined aquifer.

Unconfined Aquifer. Also known as a water-table aquifer, an unconfined aquifer is a typically the shallowest aquifer at a particular location. An unconfined aquifer is typically not overlain by a low permeability confining layer such as an aquitard or aquiclude. The upper surface of the water table is at atmospheric pressure.

Vadose Zone. The vadose zone consists of unsaturated soil or sediments above the water table. The moisture is at less than atmospheric pressure and will not flow into a well or borehole.

Water Table. The level (height or elevation) in the saturated zone at which the water pressure is equal to atmospheric pressure. The top of an unconfined aquifer is known as the water table.

10. REFERENCES

Abbas, M.J., Latif, K.H., and B.A. Ahmed, 2010a, *Groundwater Monitoring Program at Al-Tuwaitha Nuclear Research Center in Iraq,* submitted to the American Nuclear Society for the "Decommissioning, Decontamination & Reutilization (DD&R) Conference", August 2010, Idaho Falls, Idaho, 50 pp.

Abbas, M.J., Latif, K.H., and B.A. Ahmed, *Groundwater Monitoring Program at Al-Tuwaitha Nuclear Research Center, Iraq,* August, 2010, informal paper, 21 pp.

Abbas, M. J., Mubarek, M. A., and H.S. Aboud, 2008, *Geological and Hydrogeological Information of Al-Tuwaitha Nuclear Research Center, Iraq,* 7 pp.

Albright, D., Gay, C., and K. Hamza, 1999, *Development of the Al-Tuwaitha Site: What if the Public or the IAEA had Overhead Imagery?,* http://www.isis-online.org/publication/iraq/tuwaitha.html, website accessed 26 April 1999, 19 pp.

Al-Adili, A. and S. Ali, 2006, *Hydrochemical Evolution of Shallow Ground Water System Within Baghdad City – Iraq,* Tenth International Water Technology Conference, IWTC10 2006, Alexandria, Egypt, p. 1049 – 1055.

Al-Ansari, N. A., Ali, S. H., and A. S. Taqa, 1979, *Sediment Discharge of the River Tigris at Baghdad (Iraq),* Proceedings of the Canberra Symposium – "The Hydrology of Areas of Low Precipitation", IAHS-AISH Publication no. 128., December.

Al-Jiburi, H., 2011, e-mail correspondence between Dr. H. Al-Jiburi (Iraqi Geological Survey (State Company of Geological Survey and Mining) and J. R. Cochran, Sandia National Laboratories, 1 p, 12 December 2011.

Al-Jiburi, H., 2012, *A Proposed Plan for Monitoring Groundwater at Al-Tuwaitha Site During the Year 2012,* informal paper hand delivered to C. C. Lum (Sandia National Laboratories) during tour of Al-Tuwaitha on February 8, 2012, 5 pp.

Al-Musawi, F., 2010, *Radioactive Waste Management Policy and Strategy in Iraq,* Deputy Minister, Ministry for Science and Technology, Baghdad, Iraq, 24 pages, March.

Chesser, R.K., Rodgers, B.E., Bondarkov, M., Shubber, E., and C. J. Phillips, 2009, *Piecing Together Iraq's Nuclear Legacy,* Bulletin of the Atomic Scientists, May/June 2009, vol. 65, no. 3, pp.19-33.

Chesser, R. K., 2012, Texas Tech University *e-mail correspondence [Al-Tuwaitha Buildings]* to R. A. Miller, Sandia National Laboratories, 19 June 2012.

Cochran, J.R. and Danneels, J.J., 2009, Sandia National Laboratories Support of the Iraq Nuclear Facility Dismantlement and Disposal Program, SAND2009-1732, Sandia National Laboratories, Albuquerque, NM.

Dennis, M. L., Sol Shamsaldin, E., and J. R. Cochran, 2011, *Iraq Liquid Radioactive Waste Tanks Maintenance and Monitoring Program Plan*, SAND2011-6549, Sandia National Laboratories, Albuquerque, NM, 80 pp., October.

DigitalGlobe, Inc., 2011, WorldView-2 satellite imagery, resolution 0.46 meters, date of acquisition 29 March 2011.

ESRI (Environmental Systems Research Institute), 2001, ArcGIS website: http://www.esri.com/software/arcgis/, Ikonos satellite imagery, resolution 1 meter, date of acquisition 7 October 2001, website accessed 8 June 2011.

Food and Agriculture Organization, United Nations, 2011, http://www.fao.org/nr/water/aquastat/countries/iraq/index.stm, website accessed 15 May 2011.

GlobalSecurity.org, 2013, *Ash Shaykili Warehouse Complex - Ash Shaykili Nuclear Facility*, website accessed 28 February 2013.

Google Earth, historical satellite imagery for 5 May 2002, 16 July 2002, 5 November 2003, 19 August 2004, 24 June 2009, 18 August 2009, and 12 October 2010, website last accessed on 28 February 2013.

Hasson, A., 2008, *Saline Groundwater Pumping Water Change Water Quality and Management In Dry-Lands: An Experimental and Numerical Assessments, Journal of Agricultural, Food, and Environmental Sciences***,** Volume 2, Issue 1.

Heath, R. C., 1989, *Basic Ground-Water Hydrology*, Water-Supply Paper 2220, U.S. Geological Survey.

Jassim, S. Z. and J. C. Goff, 2006, editors, *Geology of Iraq*, Dolin Publishers, Prague, Czech Republic, 341 pp.

Lum, C. C., 2012a, Sandia National Laboratories, *e-mail correspondence [Iraq, Al-Tuwaitha Groundwater Borehole Locations]*, to J.R. Copland, CE2 Corporation, 17 April 2012.

Lum, C. C., 2012b, Sandia National Laboratories, *e-mail correspondence [Al-Tuwaitha Trip]*, to J.R. Copland, CE2 Corporation, 6 June 2012.

Miller, M. L., 2012, Sandia National Laboratories, *e-mail correspondence [Al-Tuwaitha Rad in Groundwater]*, to Copland J. R., CE2 Corporation, 26 June 2012.

Ministry of Science and Technology, 2011, *Draft Overarching Decommissioning and Project Management Plan for the Iraqi Decommissioning Program*, Draft Revision 5, 95 pp., June.

Ministry of Water Resources, Republic of Iraq, 2006, *Groundwater, Technical Report TR-06, Strategy of Water and Land Resources in Iraq*, 16 pp., August.

Miller, M. L., 2011, Health Physicist at Sandia National Laboratories, *personal communication* with J.R. Copland, Senior Hydrogeologist, CE2 Corporation, 29 June 2011.

MoEn, 2010, *National Report on Biodiversity in Iraq*, Ministry of Environment, Republic of Iraq, 159 pp., July.

Mutlak, S. M., Salih, B.M., and S. J. Tawfiq, 1980, *Quality of Tigris River Passing Through Baghdad for Irrigation*, Water, Air, and Soil Pollution, Volume 13, pp. 9-16.

Myers, J., 2012, *Evaluation of Analyses of Groundwater Samples from the Al-Tuwaitha Site,* The Shaw Group Inc., memorandum to J. R. Copland, CE2 Corporation, 28 March 2012, 5 pp.

National Geographic, 2011, *Baghdad After the Storm*, vol. 220, no. 1, pp. 76-101, July.

Nielsen, D.M., 2006, *Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring,* 2nd edition, Taylor & Francis Press Group, pp. 1,318.

Razzak, I. A. A., and A. H. Sulaymon, 2009, *Effects on Discharging Sewage of Baghdad to Tigris River on the Water Quality*, Engineering & Technology Journal, vol. 27, no. 16.

Saleh, D.K., 2010, *Stream Gage Descriptions and Streamflow Statistics for Sites in the Tigris River and Euphrates River Basins, Iraq*: U.S. Geological Survey Data Series 540, 146 pp.

U.S. Environmental Protection Agency, 2000, *Data Quality Objectives Process for Hazardous Waste Site Investigations,* EPA/600/R-00/007, January 2000.

U.S. Environmental Protection Agency, 2001, *EPA Requirements for Quality Assurance Project Plans,* EPA QA/R-5, EPA/240/B-01/003, March 2001.

U.S. Environmental Protection Agency, 2013, *Water: Drinking Water Contaminants – National Primary Drinking Water Regulations, National Secondary Primary Drinking Water Regulations,* http://water.epa.gov/drink/contaminants/index.cfm, website accessed 14 March 2013.

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Appendix A. Status of Buildings at Al-Tuwaitha

Building Number	Building Name in Iraqi Declaration of May 1995 (as cited in Albright *et al*., 1999)	Building Name revised by United Nations inspectors (as cited in Albright *et al*., 1999)	Bombed in 1991 (as cited in Chesser *et al*., 2009)	Building Name or Type (Chesser, 2012)	Status evaluated using March 2011 satellite imagery and Chesser (2012)
1	personnel control office			Control Office	Intact
2	restaurant			Restaurant / Commissary	Intact
3	administrative building			Administration	Intact
4	biology and agricultural labs			Biology and Agricultural Laboratories	Intact
5	head administration			Administration	Intact
6	administration			Administration	Dismantled
7	administration	training office		Administration and Training	Intact
8	training offices	external relations department		External Relations Department	Intact
9	chemical analyses labs & radiochemical labs		yes	Chemical Analyses and Radiochemistry Laboratories	Damaged
10	chemical analyses labs			Chemical Analysis Laboratories	Intact
11	telephone communication			Telephone Communications	Intact
12	engineering services workshop	engineering & neutron generator		Engineering and Workshop	Intact

Building Number	Building Name in Iraqi Declaration of May 1995 (as cited in Albright *et al*., 1999)	Building Name revised by United Nations inspectors (as cited in Albright *et al*., 1999)	Bombed in 1991 (as cited in Chesser *et al*., 2009)	Building Name or Type (Chesser, 2012)	Status evaluated using March 2011 satellite imagery and Chesser (2012)
13	IRT-5000 research reactor		yes	Russian Reactor – IRT-5000	Damaged
14	sub-station			Substation	Dismantled
15	isotope production laboratory		yes	Isotope Production Laboratory	Partially Dismantled*
16	mechanical production workshop	workshop for IRT		Mechanical Workshop for IRT-5000	Intact
17	Mechanical production workshop			Mechanical Production Workshop	Intact
18	medical analyses lab			Medical Analysis Laboratory	Intact
19	offices and stores	open air pool		Offices and Stores	Dismantled
20	offices and stores			Offices and Stores	Dismantled
21	offices and stores			Offices and Stores	Dismantled
22	hot laboratories LAMA		yes	Active Metallurgy Analysis Laboratory – LAMA	Completely Dismantled*
23	laboratory workshop building		yes	Laboratory Workshop Building	Dismantled
24	Tammuz-2 zero power reactor		yes	TAMMUZ-2 Zero Power Reactor	Damaged
25	store			Storage	Dismantled

Building Number	Building Name in Iraqi Declaration of May 1995 (as cited in Albright *et al*., 1999)	Building Name revised by United Nations inspectors (as cited in Albright *et al*., 1999)	Bombed in 1991 (as cited in Chesser *et al*., 2009)	Building Name or Type (Chesser, 2012)	Status evaluated using March 2011 satellite imagery and Chesser (2012)
26	chemical cleaning workshop			Chemical Workshop	Partially Dismantled*
27	caravan			Storage Caravan	Dismantled
28	caravans			Caravans	Dismantled
29	chemical cleaning workshop	caravan		Chemical Workshop	Damaged
30	chemical cleaning workshop			Chemical Workshop	Damaged
31	cooling tower	cooling tower for Tammuz	yes	Cooling Tower	Damaged
32	cooling tower	warehouse		Storage Warehouse	Dismantled
33	offices			Offices	Dismantled
34	offices and stores			Offices and Stores	Intact
35	Radioactive waste treatment station (RWTS)			Radioactive Waste Treatment Station – RWTS	Intact, repaired
36	store	solid waste store [solid waste storage silo]		Radioactive Waste Storage	Intact, known as Russian Silos
37	training offices	storage		Storage	Intact
38	training offices labs			Training Offices and Laboratories	Intact

Building Number	Building Name in Iraqi Declaration of May 1995 (as cited in Albright *et al*., 1999)	Building Name revised by United Nations inspectors (as cited in Albright *et al*., 1999)	Bombed in 1991 (as cited in Chesser *et al*., 2009)	Building Name or Type (Chesser, 2012)	Status evaluated using March 2011 satellite imagery and Chesser (2012)
39	store	permanent solid waste storage		Permanent Solid Waste Storage Facility	Intact
40	solid waste storage	waste storage for IRT		Russian Silos – Radioactive Waste Storage for the IRT-5000	Intact
41	control room for no. 40	nuclear instrument calibration and waste storage		Radioactive Source Shed. Instrument calibration and waste storage.	Intact
42	technical library and conference rooms			Technical Library and Conference Rooms	Intact
43	technical library and conference rooms			Technical Library and Conference Rooms	Intact
44	technical library and conference rooms			Technical Library and Conference Rooms	Intact
45	water treatment station			Water Treatment Station	Intact
46	biology and agricultural labs			Biological and Agricultural Laboratories	Intact
47	biology and agricultural labs			Biological and Agricultural Laboratories	Intact
48	biology and agricultural labs			Biological and Agricultural Laboratories	Intact
49	Biology and agricultural labs			Biological and Agricultural Laboratories	Intact
50	mechanical workshops and stores	(includes also IQZ)		Biological and Agricultural Laboratories	Intact

Building Number	Building Name in Iraqi Declaration of May 1995 (as cited in Albright *et al*., 1999)	Building Name revised by United Nations inspectors (as cited in Albright *et al*., 1999)	Bombed in 1991 (as cited in Chesser *et al*., 2009)	Building Name or Type (Chesser, 2012)	Status evaluated using March 2011 satellite imagery and Chesser (2012)
51	mechanical workshops and stores			Mechanical Workshops and Storage	Intact
52	mechanical workshops and stores			Mechanical Workshops and Storage	Intact
53	mechanical workshops and stores			Mechanical Workshops and Storage	Intact
54	mechanical workshops and stores	graphite workshop		Graphite Workshop	Intact
55	mechanical workshops and stores		yes	Mechanical Workshops and Storage	Dismantled*
56	mechanical workshops and stores			Mechanical Workshops and Storage	Intact
57	mechanical workshops and stores			Mechanical Workshops and Storage	Intact
58	cafeteria			Cafeteria	Intact
59	health physics building			Health Physics Building	Intact
60	offices		yes	Offices	Dismantled*
61	incinerator			Incinerator	Intact
62	sewage station			Sewage Station	Intact

Building Number	Building Name in Iraqi Declaration of May 1995 (as cited in Albright *et al*., 1999)	Building Name revised by United Nations inspectors (as cited in Albright *et al*., 1999)	Bombed in 1991 (as cited in Chesser *et al*., 2009)	Building Name or Type (Chesser, 2012)	Status evaluated using March 2011 satellite imagery and Chesser (2012)
63	cold material testing laboratories		yes	Cold Material Testing Laboratory	Dismantled
64	chemical waste treatment (liquids)	rad waste process building	yes	Radioactive Waste Processing	Dismantled
65	chemical waste treatment(liquids)		yes	Chemical Waste Treatment (Liquid)	Dismantled
66	chemical waste treatment (liquids)	offices/training building	yes	Chemical Waste Treatment (Liquid)	Dismantled
67	deionized water production units			Deionized Water Production Units	Intact
68	utilities	storage		Storage	Dismantled
69	utilities	oil storage		Oil Storage	Dismantled
70	utilities	Electrolytical / production of hydrogen		Electrolytic Hydrogen Production	Intact
71	utilities			Utilities	Intact
72	utilities			Utilities	Intact
73A/73B, 73C, 73D	workshops	workshop for fuel fabrication laboratory and hall for material testing	yes	Fuel Fabrication and Materials Testing	Dismantled
74	power sub-station			Power substation	Intact
75	caravans			Caravans	Intact

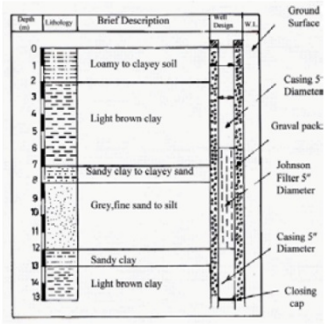
Building Number	Building Name in Iraqi Declaration of May 1995 (as cited in Albright *et al*., 1999)	Building Name revised by United Nations inspectors (as cited in Albright *et al*., 1999)	Bombed in 1991 (as cited in Chesser *et al*., 2009)	Building Name or Type (Chesser, 2012)	Status evaluated using March 2011 satellite imagery and Chesser (2012)
76	power sub-station	canteen		Cafeteria	Intact
77	utilities workshop			Utilities Workshop	Damaged
78	utilities workshop			Utilities Workshop	Dismantled
79	caravans			Caravans	Dismantled
80	nuclear physics laboratories		yes	Nuclear Physics Laboratories	Completely Dismantled*
81	cafeteria			Cafeteria	Intact
82	electronic research laboratories	electronics department & computer center		Electronic Research Laboratories and Computer Center	Intact
83	utilities			Utilities	Intact
84	utilities	chemistry & chemical engineering R&D		Chemical Engineering Research and Development	Completely Dismantled*
85	chemical research laboratories		yes	Chemical Research Laboratories	Completely Dismantled*
86	mechanical design laboratories			Mechanical Design Laboratories	Intact
87	medical center			Medical Center	Intact
88	health center			Health Clinic	Intact
89	caravans			Caravans	Dismantled

Building Number	Building Name in Iraqi Declaration of May 1995 (as cited in Albright *et al*., 1999)	Building Name revised by United Nations inspectors (as cited in Albright *et al*., 1999)	Bombed in 1991 (as cited in Chesser *et al*., 2009)	Building Name or Type (Chesser, 2012)	Status evaluated using March 2011 satellite imagery and Chesser (2012)
90	polymer chemistry laboratory			Polymer Chemistry Laboratory	Intact, with several out buildings*
A				Building (possibly temporary)	Building with peaked roof built between July 2002 and November 2003
B				Building (possibly temporary)	Building with peaked roof built between 1991 and 2001
OUT-1					burial location outside the berm (see note below)
Sewage Treatment Pond (STP)					Intact, last used in July 2002. Nearby open-air settling tanks possibly last used in July 2002.
Waste Storage Area				Waste Storage Area	used about 2007 through 2011*
Forward Operating Base				Forward Operating Base	used about 2007 through 2010, mostly dismantled*

Notes:

- The status column is based upon 12 October 2010 (Google Earth) and 29 March 2011 (DigitalGlobe) satellite imagery and also from field information (Chesser, 2012). The applicable information from Chesser (2012) is marked with an asterisk.
- "Intact" means that the roof appears consistent with previous satellite imagery and was apparently not significantly damaged by aerial bombing. Status of the building interior or contents is not known.
- Some building roofs have been renovated and are difficult to interpret. Undocumented renovations are apparent.
- Several small buildings are not identified in previous documents and are therefore not listed above.
- The sewage treatment pond (STP) was not discussed in previous Iraqi documents.
- The actual building numbers and names for Buildings A and B are not known. The letter designations (A, B, and STP) were created by the GMPP authors.
- OUT-1 is a burial location outside the berm (MoST, 2011) and is possibly near Building 90.
- Waste Storage Area and Forward Operating Base information from Chesser (2012).

Appendix B. Lithologic Descriptions and Well Diagrams for Al-Tuwaitha by Abbas *et al*., 2010a



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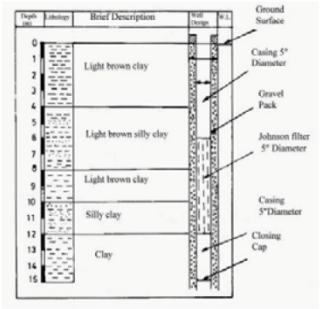
GEOLOGICAL SECTION



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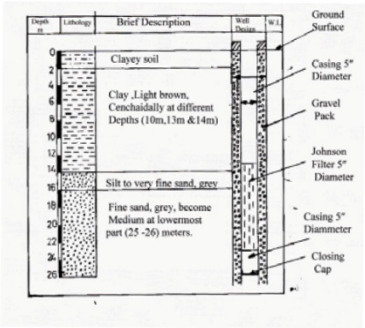

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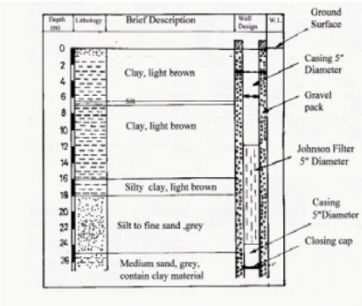

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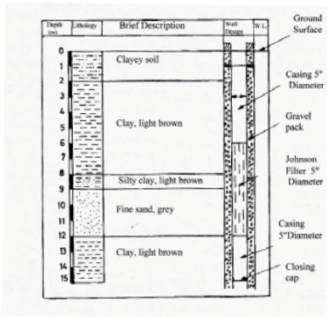
GEOLOGICAL SECTION



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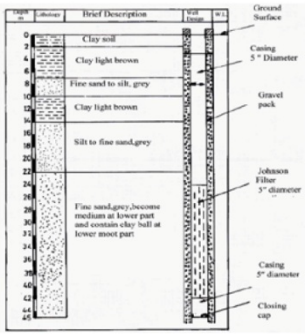
GEOLOGICAL SECTION



BOREHOLE NO. 6
GEOLOGICAL SECTION

140692.01008000 A7

Appendix C. Groundwater Elevations Measured at Al-Tuwaitha in 2002 and 2011 (Abbas *et al*., 2010a and Al-Jiburi, 2012)

Well	Screened Interval (m, bgs)	Screened Unit	TOC, Elevation (m, asl)	Water Level Measurement Date	Depth to Water (m, btoc)	Potentiometric Surface (m, asl)
Well 1	6 - 12	Shallow	32.02	2002	4.22	27.80
Well 1	6 - 12	Shallow	32.02	13 Jul 2011	5.52	26.50
Well 1	6 - 12	Shallow	32.02	12 Sep 2011	5.77	26.25
Well 1	6 - 12	Shallow	32.02	17 Nov 2011	5.57	26.45
Well 1	6 - 12	Shallow	32.02	19 Dec 2011	5.30	26.72
Well 2	6 - 12	Shallow	31.88	2002	4.21	27.67
Well 2	6 - 12	Shallow	31.88	13 Jul 2011	5.64	26.24
Well 2	6 - 12	Shallow	31.88	12 Sep 2011	5.87	26.01
Well 2	6 - 12	Shallow	31.88	17 Nov 2011	5.59	26.29
Well 2	6 - 12	Shallow	31.88	19 Dec 2011	5.19	26.69
Well 3	13 - 23	Regional	31.56	2002	3.95	27.61
Well 3	13 - 23	Regional	31.56	13 Jul 2011	5.19	26.37
Well 3	13 - 23	Regional	31.56	12 Sep 2011	5.36	26.20
Well 3	13 - 23	Regional	31.56	17 Nov 2011	5.09	26.47
Well 3	13 - 23	Regional	31.56	19 Dec 2011	4.72	26.84
Well 4	12 - 24	Regional	31.81	2002	4.02	27.79
Well 4	12 - 24	Regional	31.81	13 Jul 2011	5.17	26.64
Well 4	12 - 24	Regional	31.81	12 Sep 2011	5.35	26.46
Well 4	12 - 24	Regional	31.81	17 Nov 2011	5.11	26.70
Well 4	12 - 24	Regional	31.81	19 Dec 2011	4.76	27.05
Well 5	6 - 12	Shallow	31.59	2002	3.52	28.07
Well 5	6 - 12	Shallow	31.59	13 Jul 2011	5.71	25.88
Well 5	6 - 12	Shallow	31.59	12 Sep 2011	5.92	25.67
Well 5	6 - 12	Shallow	31.59	17 Nov 2011	5.64	25.95
Well 5	6 - 12	Shallow	31.59	19 Dec 2011	5.33	26.26
Well 6	24 - 42	Regional	31.57	2002	3.71	27.86
Well 6	24 - 42	Regional	31.57	13 Jul 2011	4.90	26.67
Well 6	24 - 42	Regional	31.57	12 Sep 2011	5.12	26.45
Well 6	24 - 42	Regional	31.57	17 Nov 2011	4.88	26.69
Well 6	24 - 42	Regional	31.57	19 Dec 2011	4.54	27.03

asl = above sea level
bgs = below ground surface
btoc = below top of casing
m = meters
TOC = top of casing

Appendix D. Geochemical Data for Groundwater Samples Collected at Al-Tuwaitha in 2002 and 2011 (Abbas *et al*., 2010a and Al-Jiburi, 2012)

Well	Sample Date	Screened unit	pH	EC (µmohs/cm)	TDS (ppm)	Ca+ (mg/L)	Mg+ (mg/L)	Na+ (mg/L)	K+ (mg/L)	Cl- (mg/L)	HCO3- (mg/L)	SO4- (mg/L)	NO3- (mg/L)	Total Hardness
Well 1	2002	Shallow	7.75	10600	6864	720	626	2050	15	2004	380	1030	0.7	
Well 1	13 Jul 2011	Shallow	6.70	6185	4330	353		528	7	1058		1100		
Well 1	17 Nov 2011	Shallow	6.01	7440	5208	456	371	540	4.5	1440	33	1750	4	2661
Well 1	19 Dec 2011	Shallow	5.90	8800	5820	144	107	530	7	1188	119	2800	4	798.7
Well 2	2002	Shallow	7.8	13000	8364	680	726	2730	23	2624	448	1092	0.75	
Well 2	13 Jul 2011	Shallow	6.20	8950	6263	348		1210	26	1955		1325		
Well 2	17 Nov 2011	Shallow	7.46	10030	7021	310	574	920	24	2450	40	2700	0.7	3125
Well 2	19 Dec 2011	Shallow	7.00	13190	8840	380	805	1260	9	2478	33	3440	6	4250
Well 3	2002	Regional	7.35	3040	1977	120	153	695	3.5	583	85	307	0.37	
Well 3	13 Jul 2011	Regional	8.50	2592	1815	56		458	8.5	828		282		
Well 3	17 Nov 2011	Regional	7.90	2851	1492	58	126	216	4.4	450	77	335	1.9	661.6
Well 3	19 Dec 2011	Regional	7.40	3940	3260	208	322	670	19	891	88	660	3	1840
Well 4	2002	Regional	7.35	3040	1977	120	153	695	3.5	583	85	307	0.37	
Well 4	13 Jul 2011	Regional	7.90	2292	1605	36		275	7.5	483		180		
Well 4	17 Nov 2011	Regional	8.01	2131	1193	66	113	196	6	315	110	340	3.1	628.3
Well 4	19 Dec 2011	Regional	7.00	6180	4326	560	488	280	30	990	128	1560	4	3400
Well 5	2002	Shallow	7.7	6960	4492	600	447.7	1173	6.3	1098	344	789	0.4	
Well 5	13 Jul 2011	Shallow	9.10	10835	7585	306		1930	37	2875		1505		
Well 5	17 Nov 2011	Shallow	6.20	15740	11092	365	968	890	20	2520	37	3200	5.3	3774
Well 5	19 Dec 2011	Shallow	6.20	16150	11460	420	1013	1540	34	4950	29	3000	4.8	5203
Well 6	2002	Regional	7.3	2820	1830	112	101.6	686	2.6	576	77	252	0.5	
Well 6	13 Jul 2011	Regional	6.90	2721	1905	50		553	8	644		385		
Well 6	17 Nov 2011	Regional	8.90	1945	1040	20	104	206	4.6	270	117	252	1.5	476.4
Well 6	19 Dec 2011	Regional	8.70	3580	2176	20	56	432	8.7	693	194	510	19	280

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Appendix E. Evaluation of Analyses of Groundwater Samples from the Al-Tuwaitha Site (Myers, 2012)

Shaw Environmental & Infrastructure, Inc.

2440 Louisiana Blvd. NE
Suite 300
Albuquerque, New Mexico 87110
Phone: 505-262-8726
Fax: 505-262-8855

Memorandum

Date: March 28, 2012

To: John Copland

From: Jonathan Myers

RE: Evaluation of Analyses of Groundwater Samples from the Al-Tuwaitha Site

This memo provides an evaluation of the chemical analyses of a set of groundwater samples obtained from the Al-Tuwaitha Site in Iraq. Six wells were sampled during July, September, November, and December of 2011, yielding a total of 24 samples. Most of the samples were analyzed for major cations (Ca, Mg, Na, and K), major anions (chloride, sulfate, bicarbonate and nitrate), total dissolved solids (TDS), electrical conductivity (EC), and the radiological constituents Bi-214, Pb-214, and K-40. Only 12 of the 24 samples were analyzed for the full suite of major cations and anions. These 12 samples were obtained during the November and December, 2011 sampling events.

Three of the wells are completed in the shallow groundwater zone which consists of 3 to 4 m of grey silt and fine sand, and is probably semi-confined. The remaining three wells are completed in the regional aquifer which consists of grey silt and fine- to medium-grained sand, and is probably also semi-confined.

A plot of EC versus TDS (Figure 1) shows good agreement between the two parameters, and also illustrates that there are large differences between the high-TDS shallow zone and the lower-TDS regional aquifer. These differences in TDS can also be seen in Figure 2 which shows box plots comparing the distributions of TDS concentrations. The shallow and regional zones have distinctly different ranges of TDS that do not overlap.

Another significant difference between the two zones is pH, which has an average of 6.75 (n= 9) in the shallow zone and 7.91 (n= 9) in the regional aquifer. A box plot comparison of the pH distributions is shown in Figure 3.

Mass balances were calculated by comparing the measured TDS to a TDS calculated by summing the analyte concentrations. Table 1 shows the measured TDS, calculated TDS, and the ratio of the calculated to measured values for the 12 samples that were analyzed

for the full suite of cations and anions. These ratios range from 0.72 to 1.0 with an average ratio of 0.9. This indicates a slightly low bias averaging ~10 percent in one or more of the specific analytes relative to the TDS results.

Another interpretation of the low ratios is the formation of hydrated salts during the drying process which can bias the TDS measurements high, depending on the water composition and the temperature of the drying oven. Magnesium precipitates as hydrated salts that become progressively less hydrated at higher temperatures. For instance, $MgCl_2 \cdot 6H_2O$ decomposes at 117° C to $MgCl_2 \cdot 4H_2O$, which decomposes at 181° C to $MgCl_2 \cdot 2H_2O$, which decomposes to the anhydrous salt at 300° C. Magnesium sulfate has similar properties, with the heptahydrate form decomposing to the monohydrate form at 150° C. The precipitation of these hydrated salts during the TDS measurements can overestimate the true TDS. However, the lack of correlation between magnesium concentrations versus the calculated/measured TDS ratios argues against this effect.

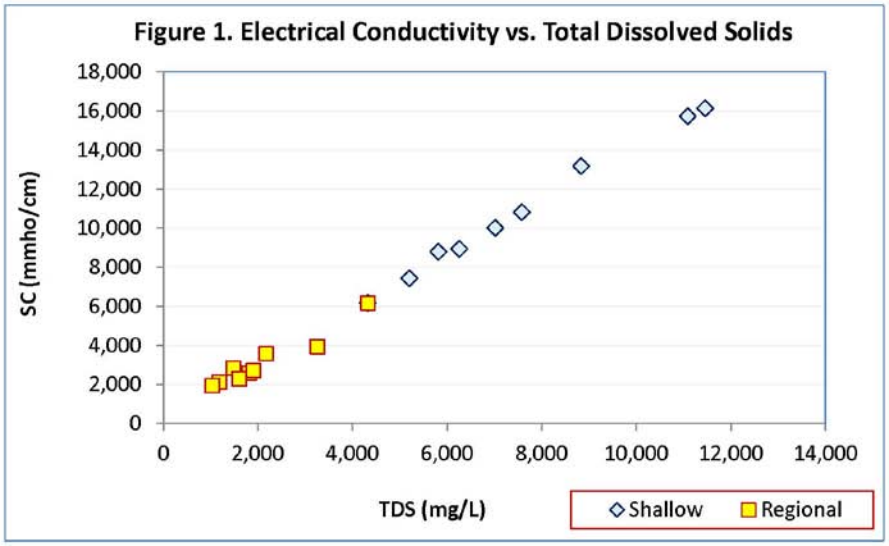
Charge balances were calculated using Geochemist's Workbench (Ver 8.0.12) for the 12 samples that were analyzed for the full suite of cations and anions. Results of the charge balance calculations are provided in the last column of Table 1 as percentages. Some of the results are close to zero percent, but the large range from -92.9 to +55.2 raises concerns regarding the accuracy of the results. Pairs of samples from the same wells show widely differing charge balances, which is difficult to explain with similar matrices.

A Piper diagram of the 12 samples that were analyzed for the full suite of cations and anions is shown in Figure 4. Shallow zone samples are shown with magenta symbols and regional aquifer samples are shown with blue symbols. Most of the samples can be described as Na-Cl type water, although a few at the edges of the range can be described as Mg-Cl or Na-SO4 dominated. The shallow and regional samples do not form separate clusters, indicating that the proportions of ions in both types of samples are similar, despite the significant differences in TDS between the two types. A possible reason for the higher TDS in the shallow zone is partial evaporation, which will increase the TDS while maintaining the same proportions of ions found in regional aquifer groundwater.

The radiologic analytes included Bi-214, Pb-214, and K-40. The Bi-214 and Pb-214 isotopes are short-lived daughters of the U-238 decay chain. Their activities were all below detection. Potassium K-40 is a very long-lived isotope that is not a member of any actinide decay chain and is not a fission product. It is naturally present as a small fixed percentage of stable K, so its activity is usually correlated with total K concentrations. Figure 5 shows the correlation between K-40 versus total K. No correlation is observed, suggesting that one or both analytes have high uncertainties.

Table 1. Comparisons of Measured and Calculated TDS and Charge Balance Results

Well	Sample Number	Date, 2011	Groundwater Unit	TDS Measured (mg/L)	TDS Calculated (mg/L)	TDS Ratio Calc/Meas	Charge Bal %
BH-1	BH-1-3	17-Nov-11	Shallow	5,208	4,599	0.88	-0.7
BH-1	BH-1-4	19-Dec-11	Shallow	5,820	4,899	0.84	-92.6
BH-2	BH-2-3	17-Nov-11	Shallow	7,021	7,019	1.00	-24.5
BH-2	BH-2-4	19-Dec-11	Shallow	8,840	8,411	0.95	-1.7
BH-5	BH-5-3	17-Nov-11	Shallow	11,092	8,005	0.72	-1.0
BH-5	BH-5-4	19-Dec-11	Shallow	11,460	10,991	0.96	-19.3
BH-3	BH-3-3	17-Nov-11	Regional	1,492	1,268	0.85	+9.2
BH-3	BH-3-4	19-Dec-11	Regional	3,260	2,861	0.88	+55.2
BH-4	BH-4-3	17-Nov-11	Regional	1,193	1,149	0.96	+19.7
BH-4	BH-4-4	19-Dec-11	Regional	4,326	4,040	0.93	+33.3
BH-6	BH-6-3	17-Nov-11	Regional	1,040	975	0.94	+23.7
BH-6	BH-6-4	19-Dec-11	Regional	2,176	1,933	0.89	-33.6



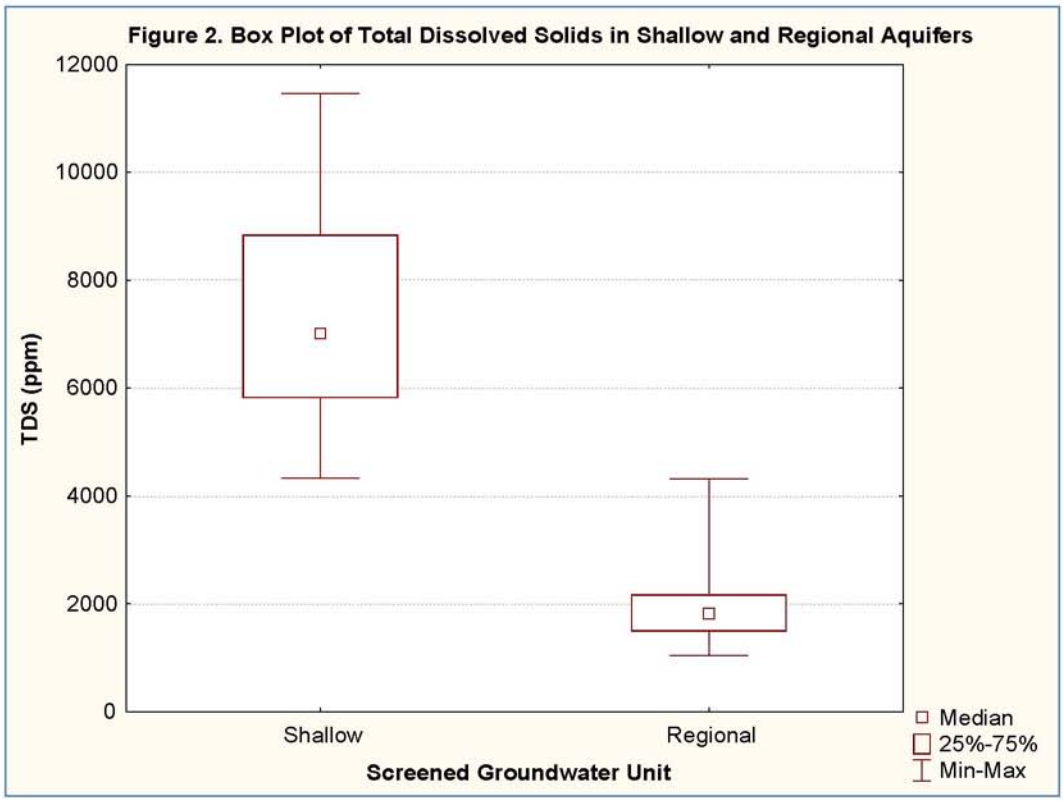


Figure 2. Box Plot of Total Dissolved Solids in Shallow and Regional Aquifers
12000
10000
8000
6000
4000
2000
0
TDS (ppm)
Shallow
Regional
Screened Groundwater Unit
Median
25%-75%
Min-Max

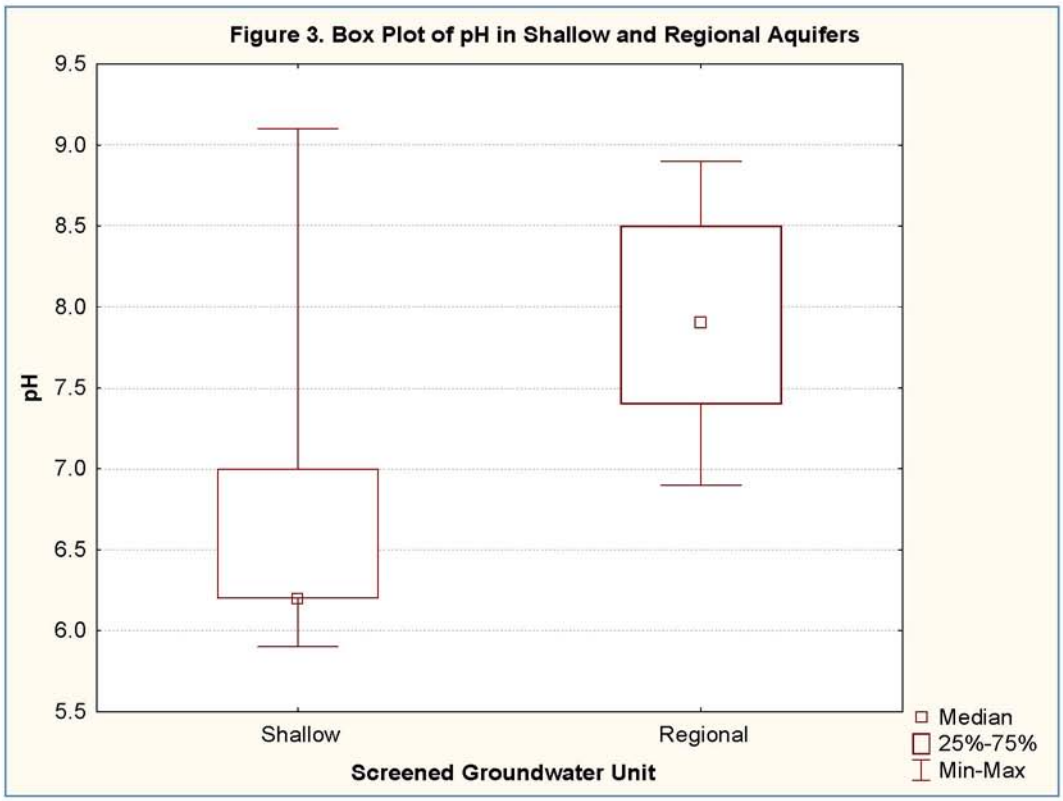
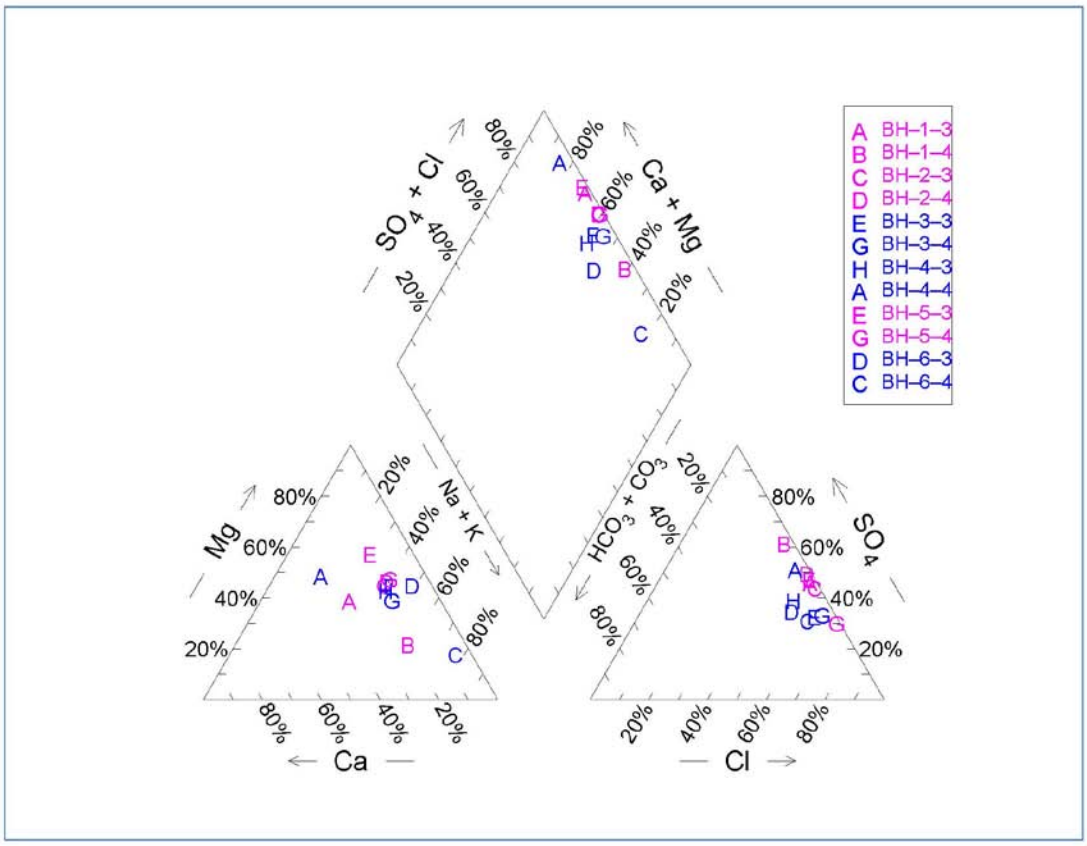
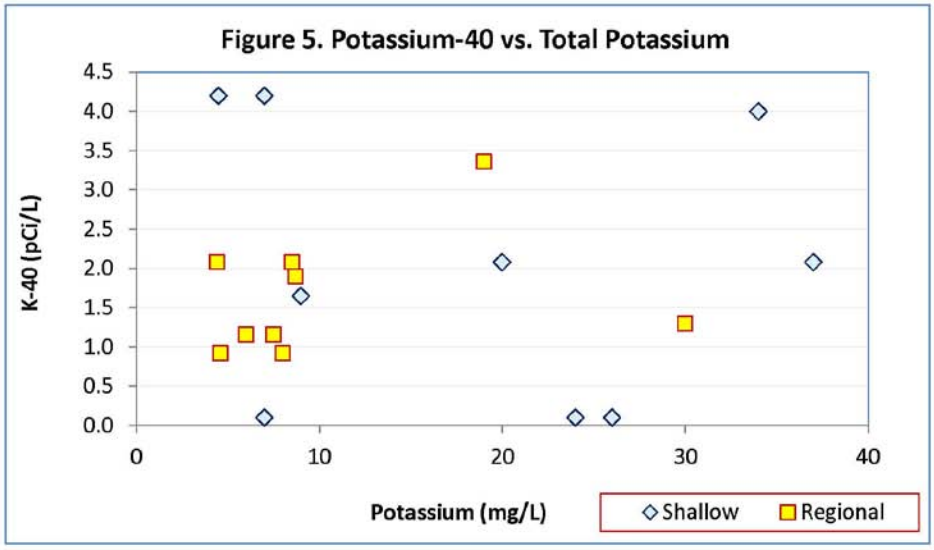


Figure 3. Box Plot of pH in Shallow and Regional Aquifers
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
pH
Shallow
Regional
Screened Groundwater Unit
Median
25%-75%
Min-Max

Figure 4. Piper Diagram of Groundwater Analyses





Appendix F. Radiochemical Data for Groundwater Samples Collected at Al-Tuwaitha in 2002 and 2011 (Abbas *et al*., 2010a and Al-Jiburi, 2012)

Well	Screened Unit	Sample Date	Bi-214 (Bq/L)	Pb-214 (Bq/L)	K-40 (Bq/L)
Well 1	Shallow	2002	BDL	10±2	n.a.
Well 1	Shallow	13 Jul 2011	BDL	BDL	4.2
Well 1	Shallow	17 Nov 2011	BDL	BDL	4.2
Well 1	Shallow	19 Dec 2011	BDL	BDL	B.D.L
Well 2	Shallow	2002	BDL	BDL	n.a.
Well 2	Shallow	13 Jul 2011	BDL	BDL	B.D.L
Well 2	Shallow	17 Nov 2011	BDL	BDL	B.D.L
Well 2	Shallow	19 Dec 2011	BDL	BDL	1.65
Well 3	Regional	2002	BDL	BDL	n.a.
Well 3	Regional	13 Jul 2011	BDL	BDL	2.08
Well 3	Regional	17 Nov 2011	BDL	BDL	2.08
Well 3	Regional	19 Dec 2011	BDL	BDL	3.36
Well 4	Regional	2002	12±3	11±2	n.a.
Well 4	Regional	13 Jul 201	BDL	BDL	1.16
Well 4	Regional	17 Nov 2011	BDL	BDL	1.16
Well 4	Regional	19 Dec 2011	BDL	BDL	1.3
Well 5	Shallow	2002	BDL	BDL	n.a.
Well 5	Shallow	13 Jul 2011	BDL	BDL	2.08
Well 5	Shallow	17 Nov 2011	BDL	BDL	2.08
Well 5	Shallow	19 Dec 2011	BDL	BDL	4
Well 6	Regional	2002	10±6	8±1	n.a.
Well 6	Regional	13 Jul 2011	BDL	BDL	0.92
Well 6	Regional	17 Nov 2011	BDL	BDL	0.92
Well 6	Regional	19 Dec 2011	BDL	BDL	1.9

n.a. = not analyzed
BDL = below detection limit (not specified in Abbas *et al*., 2010a and Al-Jiburi, 2012).

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Appendix G. A Proposed Plan for Monitoring Groundwater at Al-Tuwaitha Site during the Year 2012 (Al-Jiburi, 2012)

A proposed plan for monitoring Groundwater at Al-Tuwaitha Site during the year 2012

1- Continuous measuring of groundwater level in the monitoring wells during the year on monthly basis.
2- Measuring of water level in the Tigris River near the site on monthly basis.
3- Continuous collections of groundwater samples from the monitoring wells for chemical and radioactive analyses (mainly on quarterly basis).
4- Conduct geophysical investigations either by using Electrical Resistivity over the site or logging of the wells, in order to indicate extensions of geological beds under the site.
5- Conduct well maintenance and cleaning of the wells especially with respect to the well no. 5.
6- Install four on-site monitoring wells: one near the STP and the other three near the high potential Buildings: 15B, 35, and 40.
7- Install two off-site monitoring wells to the east of the facility, and other two wells between the facility and the Tigris River, as mentioned in the GMP plan.

Field measurements for monitoring wells in Al-Tuwaitha during July,September,November and December 2011

Date	Well No.	Depth of well(m,bgs)	TOC,Elevation(m,asl)	Depth of water(m,btoc)	SWL(m,asl)	Radiation mRem/h
13.7.2011	1	15	32.02	5.52	26.5	0.009
	2	15	31.88	5.64	26.24	0.017
	5	15	31.59	5.71	25.88	0.017
	3	26	31.56	5.19	26.37	0.012
	4	27	31.81	5.17	26.64	0.013
	6	45	31.57	4.9	26.67	0.017
Date	Well No.	Depth of well(m,bgs)	TOC,Elevation(m,asl)	Depth of water(m,btoc)	SWL(m,asl)	Radiation mRem/h
12.9.2011	1	15	32.02	5.77	26.25	0.017
	2	15	31.88	5.87	26.01	0.011
	5	15	31.59	5.92	25.67	0.012
	3	26	31.56	5.36	26.2	0.01
	4	27	31.81	5.35	26.46	0.011
	6	45	31.57	5.12	26.45	0.015
Date	Well No.	Depth of well(m,bgs)	TOC,Elevation(m,asl)	Depth of water(m,btoc)	SWL(m,asl)	Radiation mRem/h
17.11.2011	1	15	32.02	5.57	26.45	0.007
	2	15	31.88	5.59	26.29	0.008
	5	15	31.59	5.64	25.95	0.009
	3	26	31.56	5.09	26.47	0.011
	4	27	31.81	5.11	26.7	0.008
	6	45	31.57	4.88	26.69	0.01
Date	Well No.	Depth of well(m,bgs)	TOC,Elevation(m,asl)	Depth of water(m,btoc)	SWL(m,asl)	Radiation mRem/h
19.12.2011	1	15	32.02	5.3	26.72	0.013
	2	15	31.88	5.19	26.69	0.011
	5	15	31.59	5.33	26.26	0.009
	3	26	31.56	4.72	26.84	0.008
	4	27	31.81	4.76	27.05	0.017
	6	45	31.57	4.54	27.03	0.005

Notice: with respect to well no.5 it is not good working ,now it represents the lowest water level in the site, while during 2002 it is one of the highest level, especially it is the nearest to well no.6 with a distance of about 20m only. It needs to be cleaned in the near future to show if the slot of screen may closed by clay and silt which represent the main components of aquitard zone.

Chemical analysis of groundwater samples from monitoring wells of Al-Tuwaitha site during July, November and December 2011

Bh.No	pH	Ca	Mg	Na	K	SO4	Cl	HCO3	NO3	T.H.	TDS	EC	W.Type
1T	6.7	353		528	7	1100	1058				4330	6185	Na-Chloride
2T	6.2	348		1210	26	1325	1955				6263	8950	Na-Chloride
5T	9.1	306		1930	37	1505	2875				7585	10835	Na-Chloride
3T	8.5	56		458	8.5	282	828				1815	2592	Na-Chloride
4T	7.9	36		275	7.5	180	483				1605	2292	Na-Chloride
6T	6.9	50		553	8	385	644				1905	2721	Na-Chloride
Bh.No	pH	Ca	Mg	Na	K	SO4	Cl	HCO3	NO3	T.H.	TDS	EC	W.Type
1T	6.01	456	371	540	4.5	1750	1440	33	4	2661	5208	7440	Mg-Chloride
2T	7.46	310	574	920	24	2700	2450	40	0.7	3125	7021	10030	Na-Chloride
5T	6.2	365	968	890	20	3200	2520	37	5.3	3774	11092	15740	Mg-Chloride
3T	7.9	58	126	216	4.4	335	450	77	1.9	661.6	1492	2851	Mg-Chloride
4T	8.01	66	113	196	6	340	315	110	3.1	628.3	1193	2131	Mg-Chloride
6T	8.9	20	104	206	4.6	252	270	117	1.5	476.4	1040	1945	Na-Chloride
Bh.No	pH	Ca	Mg	Na	K	SO4	Cl	HCO3	NO3	T.H.	TDS	EC	W.Type
1T	5.9	144	107	530	7	2800	1188	119	4	798.7	5820	8800	Na-Sulphate
2T	7	380	805	1260	9	3440	2478	33	6	4250	8840	13190	Mg-Sulphate
5T	6.2	420	1013	1540	34	3000	4950	29	4.8	5203	11460	16150	Mg-Chloride
3T	7.4	208	322	670	19	660	891	88	3	1840	3260	3940	Na-Chloride
4T	7	560	488	280	30	1560	990	128	4	3400	4326	6180	Mg-Sulphate
6T	8.7	20	56	432	8.7	510	693	194	19	280	2176	3580	Na-Chloride

Radiation of radioactive elements (Bq / L) in groundwater samples during July / 2011

Bi-214	Pb-214	K-40	Well depth	Well No .
B.D.L	B.D.L	4.2	BH/15	1
B.D.L	B.D.L	B.D.L	BH/15	2
B.D.L	B.D.L	2.08	BH/26	3
B.D.L	B.D.L	1.16	BH/27	4
B.D.L	B.D.L	2.08	BH/15	5
B.D.L	B.D.L	0.92	BH/45	6

Radiation of radioactive elements (Bq / L) in groundwater samples during November / 2011

Bi-214	Pb-214	K-40	Well depth	Well No .
B.D.L	B.D.L	4.2	BH/15	1
B.D.L	B.D.L	B.D.L	BH/15	2
B.D.L	B.D.L	2.08	BH/26	3
B.D.L	B.D.L	1.16	BH/27	4
B.D.L	B.D.L	2.08	BH/15	5
B.D.L	B.D.L	0.92	BH/45	6

Radiation of radioactive elements (Bq / L) in groundwater samples during December / 2011

Bi-214	Pb-214	K-40	Well depth	Well No .
B.D.L	B.D.L	B.D.L	BH/15	1
B.D.L	B.D.L	1.65	BH/15	2
B.D.L	B.D.L	3.36	BH/26	3
B.D.L	B.D.L	1.3	BH/27	4
B.D.L	B.D.L	4	BH/15	5
B.D.L	B.D.L	1.9	BH/45	٦

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Appendix H. Strategy for Selecting Radionuclide Analyses for Groundwater Samples

Radionuclide	Analytical Method	Half Life	Comment
Cs-137	Gamma spectroscopy (U.S. EPA method 901.1 or equivalent)	30 years	Reasonably achievable low reporting limits
Co-60	Gamma spectroscopy (U.S. EPA method 901.1 or equivalent)	5 years	Reasonably achievable low reporting limits
Sr-90	Radiochemical separation (equivalent to U.S. EPA Method 905.0)	30 years	Perform only if high gross beta cannot be otherwise explained
Am-241	Gamma spectroscopy (U.S. EPA method 901.1 or equivalent) or by alpha spectroscopy	432 years	Reasonably achievable low reporting limits with Germanium-Lithium detectors.
Pu-238	Alpha spectroscopy	86.4 years	Perform only if high gross alpha cannot be otherwise explained
Pu-239/240	Alpha spectroscopy	24,400 years	Presence can be inferred from Am-241 gamma spec (Am-241 is decay product of Pu-239), (perform only if high gross alpha cannot be otherwise explained)
Uranium-238	Gamma spectroscopy	4.6 billion years	Recommend use of Inductively coupled plasma – mass spectrometry (ICP-MS)
Alpha emitters, total	Gross Alpha (U.S. EPA method 900.0 or equivalent)	various	Cost-effective and sensitive screening method to look for radionuclides (without isotopic identification)
Beta emitters, total	Gross Beta(U.S. EPA method 900.0 or equivalent)	various	Cost-effective and sensitive screening method to look for radionuclides (without isotopic identification)

Appendix I. List of SNL Operating Procedures Applicable to the Al-Tuwaitha GMPP

Document Number	Document Title	Revision
AOP 08-05	Long Term Environmental Stewardship (LTES) Monitoring Well Installation/Decommissioning Planning	Rev. 0
AOP 94-23	Writing Sampling and Analysis Plans	Rev. 0
AOP 95-14	Administrative Operating Procedure for Preparing Sampling and Analysis Plans, Site-Specific Sampling Plans and Field Operating Procedures	Rev. 0
AOP 97-01	Well Registry and Tracking System	Rev. 0
FOP 03-02	LTES Groundwater Level Data Acquisition and Management	Rev. 03
FOP 05-01	LTES Groundwater Monitoring Well Sampling and Field Analytical Measurements	Rev. 03
FOP 05-02	LTES Groundwater Monitoring Equipment Field Check for Water Quality Measurements	Rev. 03
FOP 05-03	LTES Groundwater Sampling Equipment Decontamination	Rev. 03
FOP 05-04	LTES Groundwater Monitoring Waste Management	Rev. 03
FOP 94-05	Borehole Lithologic Logging	Rev. 0
FOP 94-25	Documentation of Field Activities	Rev. 0
FOP 94-34	Field Sample Management and Custody	Rev. 1
FOP 94-38	Drilling Methods and Drill Site Management	Rev. 0
FOP 94-41	Well Development	Rev. 0
FOP 94-42	Integration of the Design, Installation, Rehabilitation, and Decommissioning of Environmental Restoration Wells	Rev. 0
FOP 94-43	Decommissioning of Wells	Rev. 0
FOP 94-44	Assessing & Rehabilitating Wells	Rev. 0
FOP 94-45	Designing and Installing Groundwater Monitoring Wells	Rev. 0
FOP 94-57	Decontaminating Drilling and Other Field Equipment	Rev. 0
FOP 95-23	Shallow Subsurface Drilling and Soil Sampling Using Mechanized Hydraulic Augers or the Geoprobe™ Soil Core Sampler	Rev. 0

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