WATER REUSE AND ENVIRONMENTAL CONSERVATION PROJECT

CONTRACT NO. EDH–I–00–08–00024–00 ORDER NO. 04

RUSSEIFAH PHOSPHATE PILE (AREA 3) REMEDIATION FEASIBILITY REPORT 30 MARCH 2014

30 March 2014

This document was produced for review by the United States Agency for International Development. It was prepared by AECOM.

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Submitted to:
USAID Jordan

Prepared by:
AECOM

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LIST OF ACRONYMS

AHS	Al-Hisa Phosphorite Formation
ASL	Amman Silicified Limestone Formation
BSS	Basic Safety Standards
CDM	Clean Development Mechanism
CM	Cubic Meters
EPA	Environmental Protection Agency
FA	Feasibility Assessment
GAM	Greater Amman Municipality
GCEP	General Corporation for Environmental Protection
GOJ, GoJ	Government of Jordan
H	Horizontal
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
JBC	Jordan Biogas Company
JNRC	Jordan Nuclear Regulatory Commission
JPMC	Jordan Phosphate Mines Company
K	Conductivity
LFG	Landfill Gas
MCM	Million Cubic Meters
MoEnv	Ministry of Environment
MoMA	Ministry of Municipal Affairs
MoPIC	Ministry of Planning and International Cooperation
MWI	Ministry of Water and Irrigation
NRA	Jordanian Natural Resources Authority
NWMP	National Water Master Plan
RBP	Russeifah Biogas Plant
RM	Russeifah Municipality
RSS	Royal Scientific Society
SM	Square Meters
T	Transmissivity
TENORM	Technologically-Enhanced-Naturally-Occurring Radioactive Materials
USEPA	United States Environmental Protection Agency
V	Vertical
WAJ	Water Authority Jordan
WG	Wadi Umm Ghudran Formation
WSL	Wadi As Sir Limestone Formation

1.0 INTRODUCTION

The USAID Water Reuse and Environmental Conservation Project works throughout Jordan in institutional capacity building, pollution prevention for industries, solid waste and wastewater management, and water reuse. The project is implemented by AECOM and a team of international and Jordanian partner firms. This five-year project has four primary tasks:

- Task 1 – Institutional and Regulatory Strengthening
- Task 2 – Pollution Prevention and Industrial Water Management
- Task 3 – Disposal sites Rehabilitation and Feasibility Studies
- Task 4 – Water Reuse for Community Livelihood Enhancement, including biosolids.

As part of Task 3, the project is to prepare a feasibility assessment (FA), identifying alternative techniques for rehabilitating the Russeifah site, and then, after an alternative has been selected, the project is to prepare design documents for the remediation. This report presents the results of the FA.

The Russeifah Site is composed of six individual contaminated areas. The contamination in each area is directly or indirectly the result of the development and operation of the phosphate mining industry, which began in the mid-1930s:

- **Tunnels**. The initial mining began with the hand excavation of exposed seams of phosphate-rich ore. This created a number of abandoned tunnels, called Area 5 (Tunnels).
- **Overburden**. In the mid-1950s, phosphate mining intensified through open pit mining. The material that lay on top of the phosphate-containing geological layers was removed. This material, called “overburden,” was placed in a location now called Area 6 (Overburden Piles).
- **Phosphate Stockpile**. Then the phosphate ore was excavated and placed in a large stockpile near the phosphate ore processing plant. Throughout the intervening years, portions of the stockpile were processed and hauled off; however, the bulk of the pile remains and is called Area 3 (Phosphate Stockpile).
- **Landfill**. As a result of the excavation of the phosphate ore, a large-deep open pit remained. In the mid-1980s, the Greater Amman Municipality (GAM) began using a portion of the open pit as a solid waste landfill. This landfill operation continued until 2003, when the landfill operation was curtailed. The resulting filled area of the open pit is referred to as Area 1 (Landfill).
- **Pit**. The unfilled area of the open pit is referred to as Area 2 (Pit).
- **Lagoon**. During the processing of phosphate, the process wastes were disposed of into a small wadi which drained to the Zarqa River causing sedimentation and complete blockage of the wadi. As a result, a stormwater drainage lagoon was created, called Area 4 (Lagoon).

With the development of the phosphate mining industry, the town of Russeifah saw rapid population growth. As a result, the residential area is encroaching on Areas 3, 4 and 5, while businesses and industry are pressing on Areas 1, 2 and 6. None of the areas is now in direct use by the phosphate industry.

The primary focus of this FA is the remediation and beneficial use of Area 3 (Phosphate Stockpile). The remaining areas are the subjects of other reports.

This FA follows a pre-FA also prepared by the project team. This FA provides background and other information about existing conditions at Area 3; describes remediation alternatives; evaluates these alternatives; and recommends a subset of alternatives for both remediation and beneficial end use. The appendices provide supplementary information and data.

This FA is based on review of the available reports and documents; data collection; field visits; meetings with the relevant authorities; discussions with the stakeholders; and detailed field investigations, including a topographic survey, a geotechnical investigation, and a radiological filed assessment study. The purpose is to inform decisions about the area, leading to the use of environmentally advantageous techniques to remediate the site as efficiently as possible, minimize environmental harm, and protect the health of future site users and neighbouring areas.

1.1 Problem Statement

The Russeifah Area 3 (Phosphate Stockpile) seen in Figure 1-1 consists of a large phosphate ore stockpile, consisting mainly of low-grade phosphate. The stockpile's volume is approximately 4.5 million m^3, and it covers an area of 350,000 m^2. It is a result of the aggressive open pit mining conducted between 1963 and the mid 1980's which caused this and other dramatic changes in the topography.

Figure 1-1: Phosphate Stockpile

The phosphate ore stockpile has become an aesthetic, environmental and health concern over the years. It poses risks associated with slope stability and radiation hazards.

The average concentrations of the ore material found throughout the site exceed the International Atomic Energy Agency (IAEA) exemption criteria and thus pose potential radiation threats to the neighboring communities and future users of the site.

Slope stability analyses showed that the factors of safety for the representative sections were generally below the acceptable limits. This makes the greater part of the Area unsafe according to established criteria and presents the need for remediation measures to provide slope stability.

The Russeifah region continues to grow in population. There is a need to remediate the Area not only from public aesthetics and environmental perspectives, but also from the perspective of beneficial use. The ultimate remediation of Area 3 (Phosphate Stockpile) will significantly improve the quality of life for the residents of Russeifah. The objective of this FA is to establish alternatives for the remediation of Area 3.

1.2 Report Organization

This report develops an overall framework for the systematic rehabilitation of the phosphate stockpiles. Section 2 identifies the authorization. Section 3 presents the site background, in terms of climate, geology, history, and previous studies; it also outlines the existing conditions, operations and relevant legal framework. Section 5 presents the field investigations conducted by the project team. Section 6 sets forth the remediation action planning, including site issues and remediation objectives. Section 7 presents the suggested remediation alternatives. Section 8 presents the associated cost estimates. Finally, Section 9 presents a comprehensive summary.

2.0 AUTHORIZATION

This report is prepared as a sub-task of the USAID Jordan Water Reuse and Environmental Conservation Project (Project) to provide consulting engineering services to the Government of Jordan (GoJ) at specific targets consistent with USAID's Strategic Objective to achieve "Enhanced Integrated Water Resources Management."

Work on the project is authorized under Order Number 4 in accordance with USAID Contract Number EDH-I-00-08-00024-00 for Global Architect-Engineering Infrastructure Services, as issued to AECOM Technology Corporation (AECOM).

The authorization specified that the FA was to be completed from available records, reports, and data, using practical guidance and experience to develop and evaluate alternatives, and selecting a recommended plan to remediate and rehabilitate the site for possible beneficial use.

3.0 BACKGROUND

3.1 Location

The City of Russeifah is located in the Zarqa Governorate, 15 km northeast of Amman, in the middle of Jordan and north of the highway connecting Amman and Zarqa. The city is approximately 665 m above sea level, with an approximate latitude and longitude of 30.0167°N and 36.05°E. The general location can be seen in Figure 3-1.

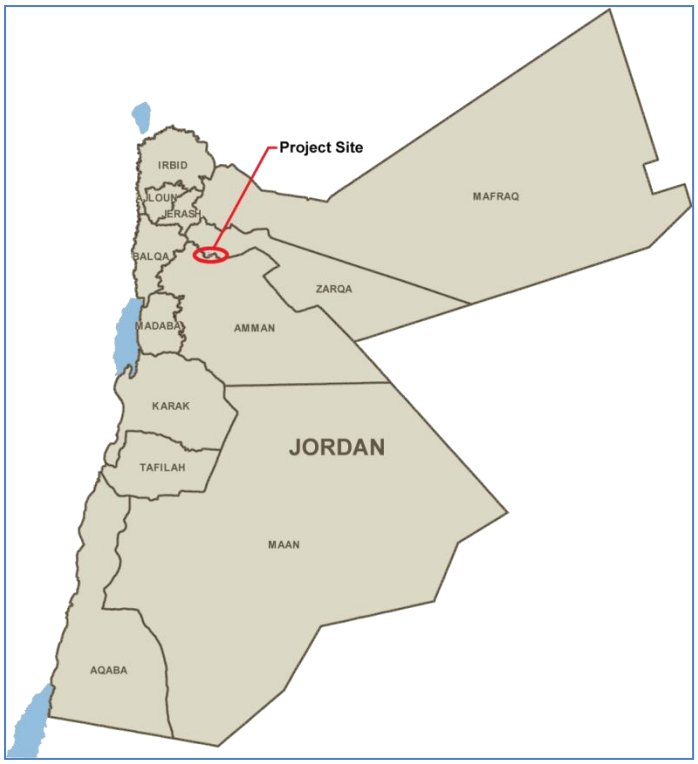

Figure 3-1: General Site Location

The phosphate mining area within Russeifah was one of the largest mining areas in Jordan. The Jordan Phosphate Mines Company (JPMC) was established in 1952 and was granted a concession area of approximately 13,478 donum. The southern part of the concession area, with an approximate area of 10,355 donum, falls within the border of GAM. The remaining 3,123 donum are within the borders of Russeifah Municipality (RM). Of the total concession area, approximately 2,720 donum has been abandoned and requires rehabilitation and/or redevelopment (RSS,1995); it is divided into the following six areas:

- Area 1: Russeifah landfill
- Area 2: Mining pit
- Area 3: Phosphate ore pile
- Area 4: Lagoon
- Area 5: Tunnels
- Area 6: Overburden piles

Each area is shown in Figure 3-2. The primary purpose of this report is to present the remediation and feasibility options for Area 3. The rehabilitation and feasibility options for the other sites are presented in other separate reports.

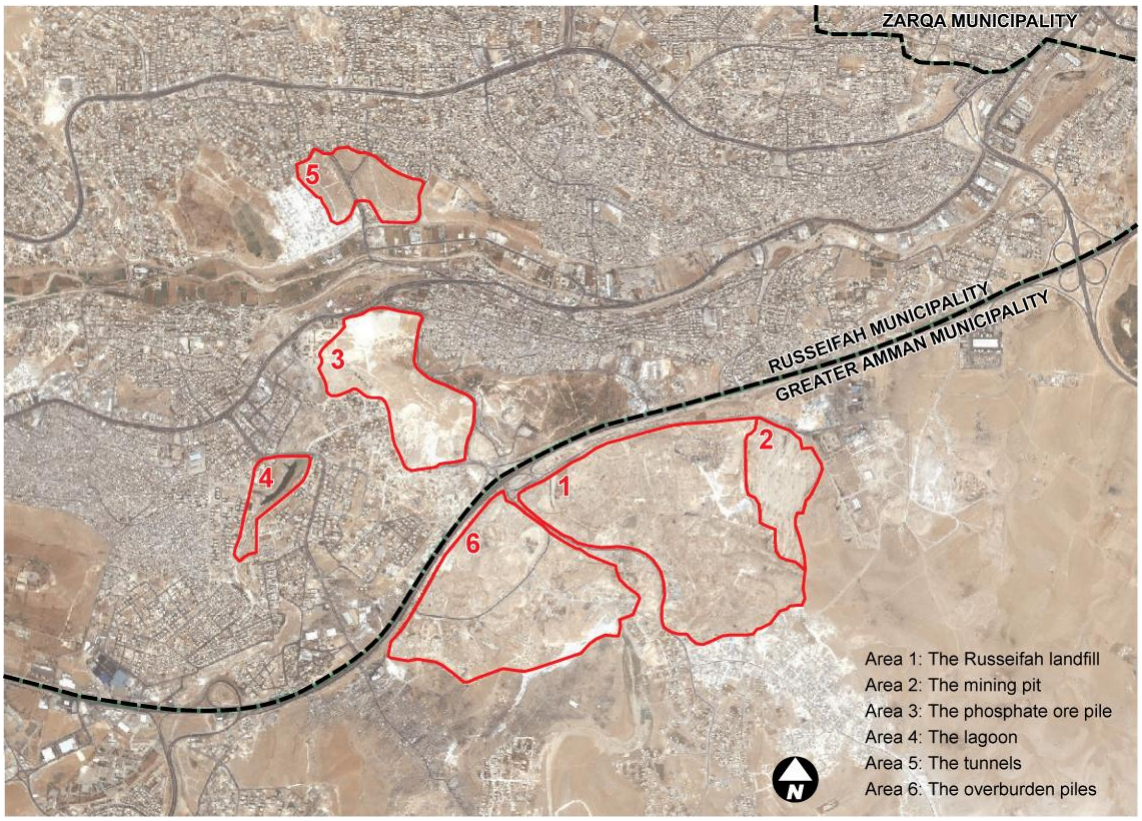

Figure 3-2: Russeifah Site Areas

3.2 Controlling Organizations

Several entities are directly or indirectly involved in managing and/or governing the phosphate stockpile in the Russeifah phosphate mining area. These entities include RM, Ministry of Environment (MoEnv) and the JPMC, in addition to several other entities.

Responsibility for this pile area overlaps among the different ministries, and no single entity has the authority to decide the fate of this site. Therefore, at the request of the Jordanian Prime Minister's office, on 12 August 2013, a technical committee was formed to study the issues related to the phosphate areas. This technical committee consisted of representatives from RM, MoEnv, GAM, JPMC, Department of Land and Surveying, and the Ministry of Planning and International Cooperation (MoPIC). The committee reviewed previous reports and studied proposals from all the committee members and agreed on the following recommendation for Russeifah Area 3:

JPMC will be given the opportunity to use the phosphate ore in the pile, but such use is to be under strict environmental dust control conditions. JPMC would be required to prepare a technical study for the rehabilitation of the phosphate piles and present it to MoEnv for approval. This study is to include the following:

- Description of the technical and environmental mechanism for using the ore material and the time frame for implementation
- Statement of financial returns from the proceeds of the use, which should be allocated to rehabilitate the area of Russeifah

If JPMC does not agree to conduct the use of the ore according to the environmental provisions set out by the MoEnv concerning dust control and environment management

during project implementation, the MoEnv has the right to decide on the fate of the pile, in accordance with the recommendations of this FA.

3.3 Ownership

Ownership of the phosphate ore stockpile is divided mainly between the treasury of the Hashemite Kingdom of Jordan and the JPMC. The detailed ownership of the project areas can be better seen on the Ownership Map in Appendix A.

3.4 Previous Reports

Several studies have been prepared previously for the Russeifah site. Of these, the following studies and reports were reviewed:

Russeifah Phosphate Mining Site Environmental Assessment, 2006, Tolaymat T. (USEPA/USAID, 2006). Prepared by the US Environmental Protection Agency for the USAID, this report includes an Environmental Assessment and Remediation Plan.

Reduction Of Methane Emissions From Russeifah Landfill, 2006 Clean Development Mechanism (CDM) - Project Design Document Form (CDM-PDD) Version 03.1 (UNFCCC, 2006). The report provides a general description of LFG system at the Russeifah landfill and the planned expansions and improvements.

Rehabilitation Of Phosphate Mining Concession Lands, 2003 (GAM, 2003)
Prepared by GAM, the report evaluates the existing conditions at the site in terms of land ownership and recommends possible land uses for the area.

Development of Phosphate Mining Concession Area in Russeifah, RSS, 1995 (RSS, 1995). Prepared by the Royal Scientific Society (RSS), the report describes the current conditions at the mining concession area and analyzes possible future land uses of the area. This study has been presented in the form of one primary report discussing the development plan and four other specified sub-studies that include:

- Sub-Study 1: Social and Economic Study
- Sub-Study 2: Geological Study
- Sub-Study 3: Structural Study
- Sub-Study 4: Environmental Study

3.5 History

Phosphate ore was discovered in Russeifah at the beginning of the 20th century, during the construction of the Hijaz Railway in 1903. Commercial extraction of phosphate ore began in 1934, when individuals and small companies hand excavated the ore by “tunneling” along an exposed phosphate seam. The resultant hand-dug tunnels are horizontal, somewhat cave-like. This process continued until 1952, when JPMC was established and took over phosphate extraction by means of the “open pit mining” approach (RSS,1995). Between 1963 and the mid 1980’s, an area of approximately 13.5 km^2 underwent aggressive “open pit mining,” which resulted in dramatic changes to the topography; alteration of the natural watershed flow by the creation of the deep mining pits found in Areas 1 and 2; the creation of overburden/reject piles seen in Area 6; and a large pile of low grade phosphate ore present in Area 3 (USEPA / USAID, 2006).

During the mid-1980’s, deposits of high grade phosphate ore were found in southern Jordan at Al Hassa, Al Abiad and Ehshidiya. As these new areas were developed, the mining

activity at Russeifah became limited, with most by-products of the mining activities left behind, including the overburden piles, low grade phosphate ore pile, tunnels and pits.

In 1986, GAM started using the open mining pit in Area 1 for solid waste disposal. This area later was referred to as the Russeifah Landfill. The landfill, considered one of the largest landfills in Jordan, sits on approximately 800 donum and served Amman, Zarqa, Russeifah and other adjacent cities, receiving about 2100 metric tons/day of solid waste until 2003. Additionally, in 1986, a southwest portion of the landfill was used by GAM for liquid waste disposal. This liquid waste disposal continued until 1994 (GAM, 2003 and RSS, 1995).

Prior to the closure of the solid waste landfill, Jordan Biogas Company (JBC) had established in 1998 the Russeifah Biogas Plant (RBP). The RBP included an organic digestion unit, a Landfill Gas (LFG) collection system and an electrical generation facility.

3.6 Climate

The climate of Jordan in general is of East Mediterranean type, characterized by warm, dry summers and mild, wet winters. Annual average temperatures range from 12 - 25°C, reaching up to 40°C in summer. Rainfall annual values vary widely within the area, ranging from 50 mm in the desert and 800 mm in the northern hills. The climate of the study area is dry hot in summer, with westerly winds. During the winter months it is cool and rainy, with occasional winter frost. The average temperature increases towards the south-eastern parts (desert areas), while it decreases towards western parts (hills). Table 3-1 presents the meteorological parameters obtained from the Amman Airport Meteorological Station, which is the nearest station to the study area.

Table 3-1: Meteorological Parameters at the Study Area

Amman Airport Meteorological Station: E 35 59', N 31 59', Elevation= 780 m (2000-2007)								
	Mean Air Temp "C°"	Mean Total Rainfall Amount "mm"	Mean No. of Rainy Days (Rainfall Amount >=0.1 mm)	Total Evaporation, Class A Pan "mm"	Daily Mean Relative Humidity "%"	Mean Wind Speed "Knot"	Prevailing Wind Direction "Degree"	Mean Pressure at Station Level "Hpa"
Jan	9.20	58.16	10.88	57.36	73.85	4.73	227	928.00
Feb	10.21	61.16	10.99	71.03	72.35	5.63	231.375	926.53
Mar	13.88	31.23	6.25	121.00	62.84	5.18	256.25	925.75
Apr	17.46	16.23	4.63	173.10	53.84	5.93	262.375	924.30
May	22.34	4.46	1.83	274.36	43.60	5.73	267.375	923.75
Jun	25.46	0.00	0.01	318.80	42.59	6.04	283.75	922.55
Jul	27.41	0.00	0.00	356.24	43.30	6.84	277.75	920.80
Aug	27.29	0.00	0.00	316.17	49.25	5.54	284.75	921.56
Sep	25.20	0.04	0.01	241.54	53.64	4.39	287.125	924.64
Oct	22.01	2.79	2.16	175.43	56.08	3.11	265	926.86
Nov	15.38	24.49	4.91	97.17	61.35	3.46	209.25	928.44
Dec	10.45	48.38	7.68	61.73	69.81	4.01	216.125	928.70
Yearly	18.85	246.93	50.59	777.59	56.88	5.05	268.00	925.16

Source: Amman Airport Meteorological Station

Precipitation is concentrated during the winter months from October to May, while the summer months are essentially dry. The average annual precipitation is about 247 mm/year, and the area is classified as an arid region. Daily precipitation values from 1923 to 2007 were analyzed to calculate the mean monthly precipitation, as shown in Figure 3-3.

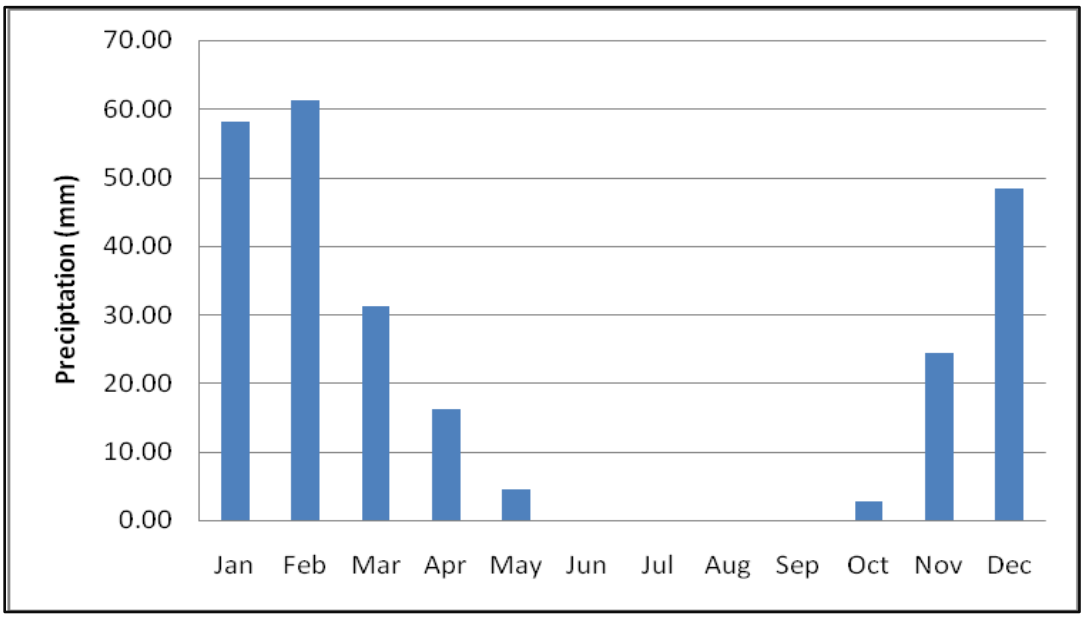

Figure 3-3: Mean Monthly Precipitation (mm) in the Study Area

3.7 Geology

The project site (Area 3) is totally covered by artificial fill materials composed of old excavated phosphate mines waste products with approximate thicknesses in the range of 1-40m. According to the available geological maps of the project area at a scale of 1:50,000 (AZ ZARQA sheet no. 3254-III, Geology by: Mohammad Abu Qudaira, 2001), the geological formations at the project area belong to the Late Cretaceous Ajlun and Balqa groups. Quaternary Pleistocene and Holocene sediments also cover part of the project area; a general geological map of the project site can be seen in the map in Figure 3-4 below.

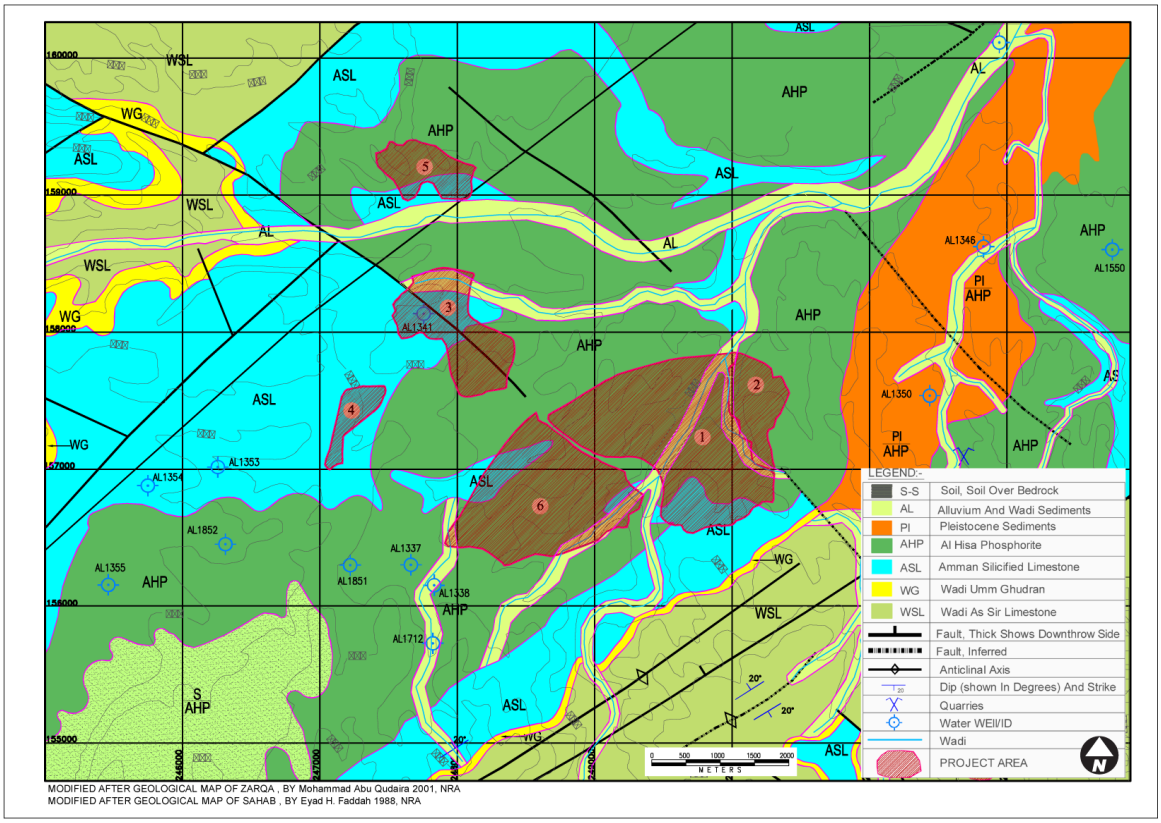

Figure 3-4: General Geological Map of the Project Area

The sequence of the exposed geological formations in the area is characterized by the main following formations:

- Alluvial Deposits
- Amman Silicified Limestone Formation (ASL) and Al Hisa Phosphorite (AHS)
- Wadi Umm Ghudran Formation (WG)
- Wadi As Sir Limestone Formation (WSL)

These are described in more details next.

Alluvial Deposits

The superficial deposits comprise alluvial (wadi) sediments. The thicknesses, distribution, physical, chemical and mineralogical properties of the superficial deposits depend mainly on the type of the parent material, time, climate and topography.

The soil deposits are formed by the dissolution of Cretaceous bedrock and consist of three parts: upper, middle and lower. The upper part of the soil is dark to grayish brown, soft to stiff silty clay and containing gravel, cobbles, and boulders of chert and silicified limestone. The middle part of the soil is brown, soft to firm silt. The lower layer is reddish brown, soft to firm silty clay containing angular gravel, cobbles and boulders of chert.

Amman Silicified Limestone Formation (ASL) and Al Hisa Phosphorite (AHS)

These formations consist of gray to brown, thin to medium bedded chert, exhibiting a variety of textures ranging from homogenous to brecciated and inter-bedded with limestone, dolomite limestone, marl, silicified chert and phosphate. The thickness of the ASL formation reaches up to 40m while that of the exposed part of the AHS formation reaches up to 20m. The ASL formation is characterized by synedimentary andulations which were caused by tectonic processes simultaneously with sedimentation. The decrease in chert content and

increase in trace fossils including fossils of bivalves, gastropods and ammonites characterize the AHS formation. These two formations were deposited in sub tidal to shallow shelf environment.

Wadi Umm Ghudran Formation (WG)
This formation is named after Wadi Umm Ghudran Ed Dib located south east of Irbid. WG formation consists of an upper and a lower part. The lower part consists of thinly bedded yellow to white grey locally pink grey, soft, massive chalky limestone while the upper part consists of limestone and chalky marl that is typically pink to yellow grey, hard, medium to thin bedded, fossil-ferrous to coquinal limestone with thin bands or concretions of chert alternating with yellow to white grey chalky marl. This formation forms distinctive yellow to white grey gentle slopes between the underlying Wadi As Sir and the overlying Amman Silicified Formation.

Wadi As Sir Limestone Formation (WSL)
This formation is named after Wadi As Sir town located west of Amman. It consists of three units: lower, middle and upper. The lower unit is comprised of dolomite, dolomitic limestone and locally recrystallized limestone. The bed of the lower unit is characterized by its red color which is due to the presence of secondary iron oxides. The middle unit of this formation consists of relatively soft marly limestone and limestone. The upper unit consists of thick-bedded to massive limestone including fossil-ferrous beds. Wadi As Sir formation is rich in calcite veins and thin beds of oysters. This formation forms steep slopes and cliffs of limestone of grey-weathering colors intercalated with marly limestone and marl.

3.8 Hydrogeology

3.8.1 General Hydrogeology

The groundwater aquifers in Jordan are classified into three main categories. These are the Deep aquifer complexes, Middle aquifer complexes and Shallow aquifer complexes. The latter is considered the most exploited (Environmental Profile of Jordan, 2006). In Jordan, a total of 12 groundwater basins were identified, based on the configuration of renewable groundwater divides. Figure 3-5 shows these groundwater basins. The arrows represent the direction of flow of the main renewable groundwater in the upper aquifer system (JICA, 2001).

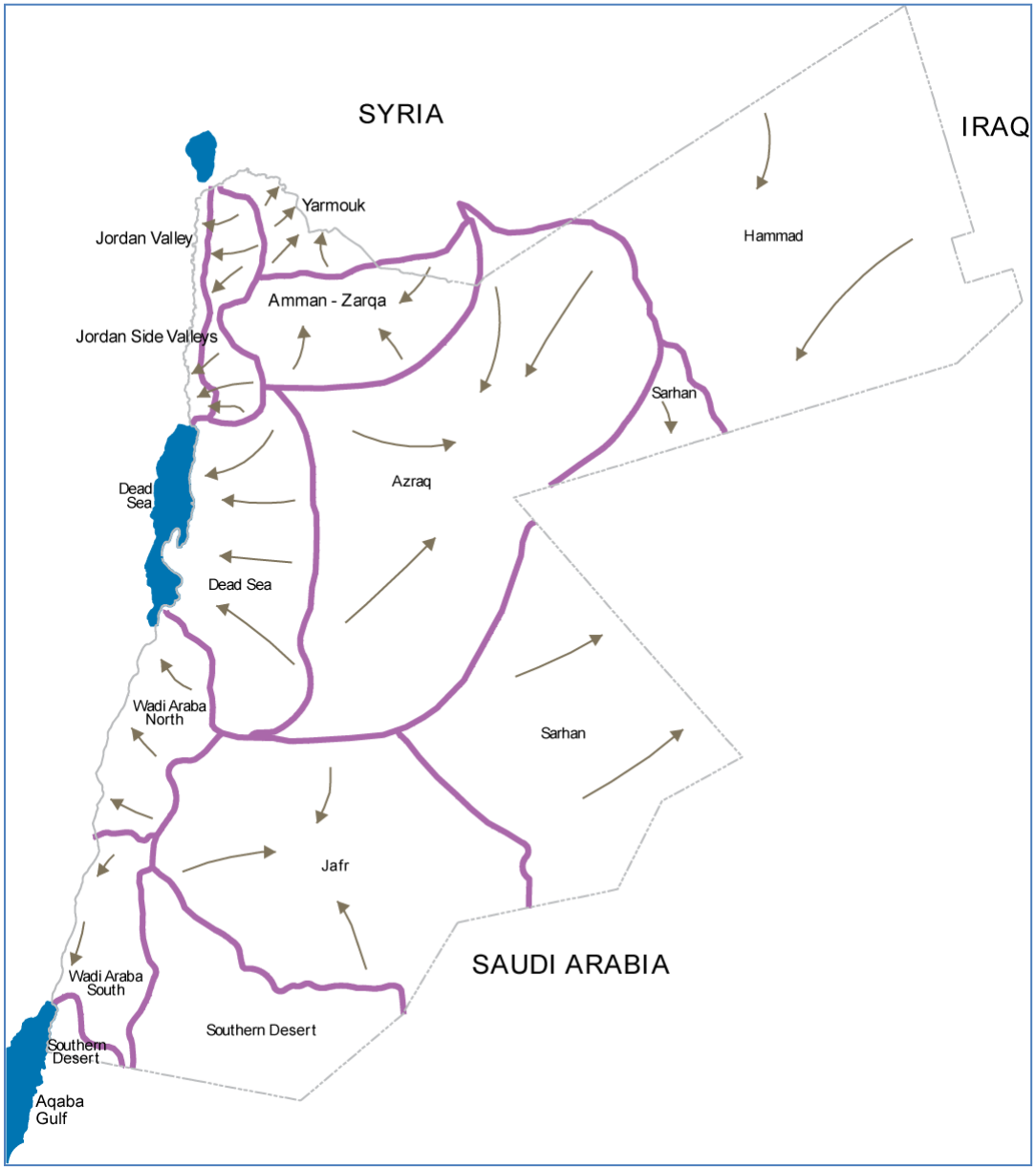

Figure 3-5: Groundwater Basins in Jordan

Within the 12 identified groundwater basins, only the southern aquifer at Disi area is considered nonrenewable, while the remaining 11 are considered renewable aquifers. According to the National Water Master Plan (NWMP) of Jordan, 2006, the primary over-exploited aquifers include Amman-Zarqa, Yarmouk, Dead Sea, Jordan Valley, Jafr and Azraq Basins.

3.8.2 Hydrogeology of the Study Area

The project area falls within the Amman-Zarqa Groundwater Basin. The basin is considered one of the most renewable groundwater basins in Jordan. Its extent is large and continuous, with a relatively high permeability. The two main aquifers in the Amman-Zarqa basin are the Amman/Wadi Sir formation (B2/A7), known as the Upper Aquifer, and the Hummar (A4) formation, to the west of Amman, known as the Lower Aquifer. Table 3-2 and Figure 3-6 summarize the geological and hydrological classifications of rock units in the Amman-Zarqa area.

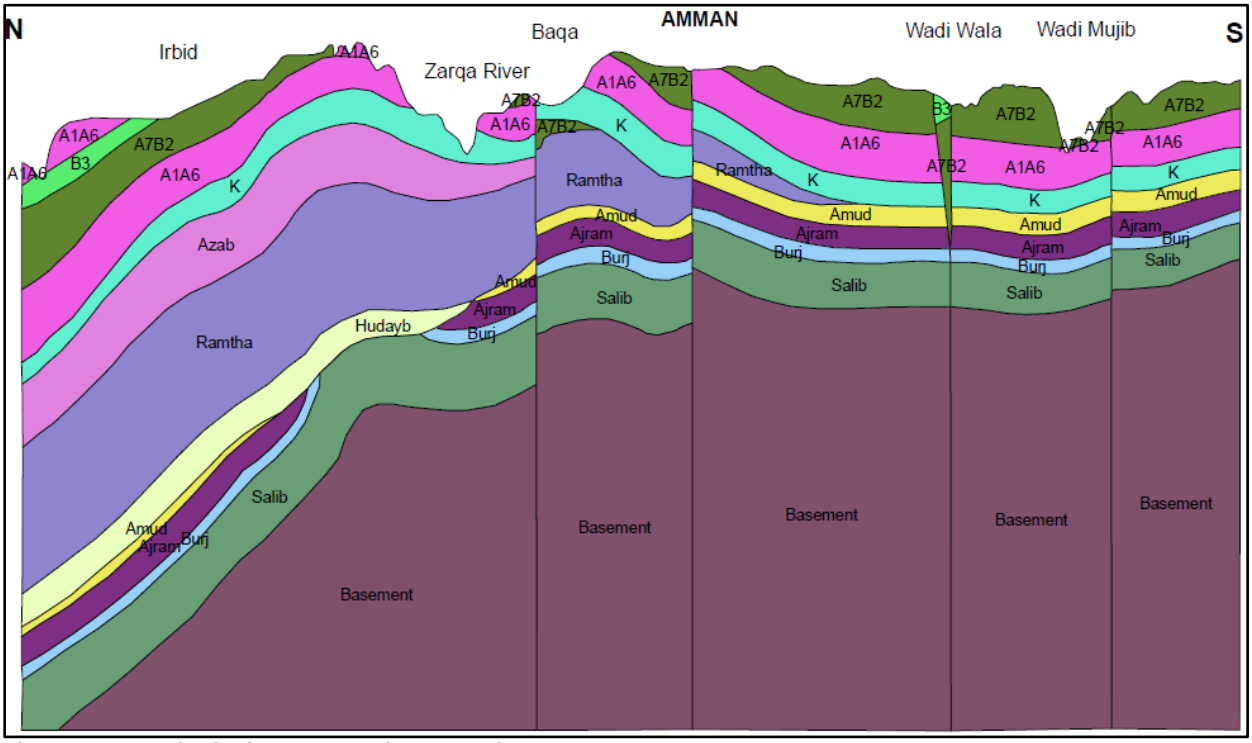

Figure 3-6: **Geological Cross Section Covering Amman – Zarqa Area**
(Adapted from WAJ FS/ESIA for Zarqa Governorate Water Wells Rehabilitation)

Table 3-2: Geological and Hydrogeological Classification of the Rock units in Amman - Zarqa Area

Epoch	Age	Group	Formation	Symbol	Rock Type	Thickness(m)	Aquifer Potentiality	Permeability (m/s)
Upper Cretaceous	Holocene	Balqa	Alluvium	Qal	Soil, sand and gravel	10-40	Good	$2.4x10^{-7}$
	Pleistocene		Basalt	V	Basalt	0-50	Good	-
	Mastrichtain		Muwaqqar	B3	Chalk, marl and chalky limestone	60-70	Poor	-
	Campanian		Amman	B2	Chert, limestone with phosphate	80-120	Excellent	10^{-5} to 3×10^{-4}
	Santonian		Um Ghudran	B1	Chalk, Marl and Marly limestone	15-20	Poor	-
	Turonian	Ajlun	Wadi As Sir	A7	Hard crystalline limestone. dolomitic and some chert	90-110	Excellent	$1x10^{-7}$ to $1x10^{-4}$
	Cenomanian		Shueib	A5-6	Light grey limestone interbeddedwithmarls and Marly limestone	75-100	Fair to poor	$6.3 x10^{-5}$ to$7.2 x10^{-4}$
			Hummar	A4	Hard dense limestone and dolomitic limestone	40-60	Good	8.1×10^{-7} to $7.6 x10^{-4}$
			Fuheis	A3	Gary and olive green soft marl. marly limestone and limestone	60-80	Poor	5.3×10^{-7} to 1.7×10^{-5}
			Na'ur	A1-2	Limestone interbedded with a thick sequence ofmarl and marly limestone	150-220	Poor	2×10^{-8} to 3.1×10^{-5}
Lower cretaceous	Albian–Aptian		Kurnub	K	Massive white and varicoloured sandstone with layers of reddish silt and shale	300	Good	$6.9 \times 10^{-3}$to 5.2×10^{-2}

Source: El-Naqa, 2006

Recharge of the B2/A7 aquifer occurs in the western highlands. Its main outcrop areas generally coincide with the area of high precipitation, which is the main recharge source for the aquifer. Rainfall reaches 400 mm/year to the west of Amman, whereas it rarely exceeds 150 mm/year in the study area. The regional groundwater flow in the B2/A7 is influenced by the recharge/discharge areas, the topography, and the structural characteristics in the region. A main recharge mound exists a few kilometers to the west of Amman, and on the south-western side of the project area. A part of the water flows towards the west and increases the discharge level of the springs in the Wadi Sir area. The rest of the groundwater flows north-eastward down the Amman-Zarqa syncline, recharging the upper aquifer and/or flowing further to the east (Kuisi,1992), as illustrated in Figure 3-7.

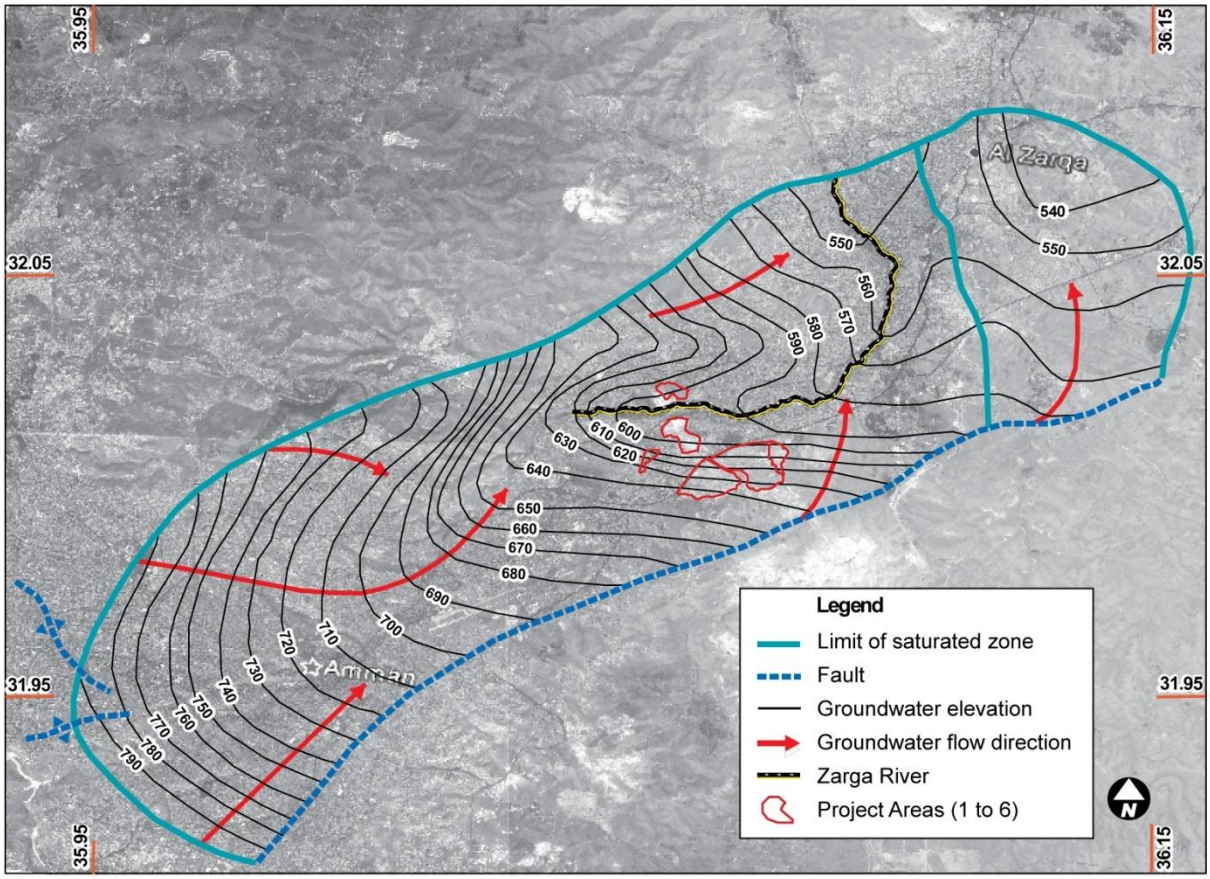

Figure 3-7: Regional Groundwater Contour Map of the (B2/A7) Aquifer (Kuisi, 1992)

The Amman-Zarqa Basin includes the fastest growing region in Jordan, in terms of both industry and population. Groundwater is the primary water supply source in the basin. The NWMP, 2006, estimated the safe yield of the basin to be in the range of 60-70 MCM/year. This calculation was based on the estimated recharge and base flow depletion as summarized in Table 3-3 below.

Table 3-3: Calculation of Safe Yield for Amman-Zarqa Groundwater Basin

Item	Volume in MCM/year
Recharge from Rainfall	72
Inflow from Syria	+30
Base flow	−40
Estimated safe yield	=62
Range of safe yield	60 to 70

Source: National Water Master Plan, 2006

Groundwater well extraction reached its peak in the year 1996, with approximately 161 MCM/year. It decreased by 15% in year 2001 to 138 MCM/year. This extraction rate is twice as high as the safe yield (NWMP, 2006). As a result; MWI has developed a stepped reduction strategy for groundwater extraction so as to reach the safe yield by the year 2020.

Using pump test data obtained from the MWI databank (El-Naqa et al., 2006), the hydraulic parameters of some groundwater wells near the Russeifah landfill were calculated. The results are shown in Table 3-4, and the locations of groundwater wells near the Russeifah landfill are shown in Figure 3-8.

The transmissivity (T) value of the B2/A7 aquifer system ranges from 33.9 to 409 m^2/day. Knowing the saturated thickness of the aquifer, it was possible to estimate its hydraulic conductivity (K), which is found to range from 0.38 to 5.18 m/day. The groundwater velocity can be calculated on the basis of the hydraulic conductivity and the hydraulic gradient values. The hydraulic gradient of the area was calculated based on difference in head of three groundwater monitoring wells inside the landfill and was found to be 2.0×10^{-3}. Assuming an aquifer porosity of 0.35, the groundwater velocity was found to be 0.029 m/day (Tarazi et al., 2006).

The static water levels recorded in 2006 at various groundwater wells near the Russeifah landfill site were found to range between 30 and 60 m (El-Naqa et al., 2006). Recent static water level data was obtained from the Water Authority of Jordan (WAJ) (2010) for the Amman - Zarqa basin and found to range from 30 to 50 m.

Table 3-4: Hydraulic Parameters of Selected Groundwater Wells in the Study Area

Code	Name	East	North	SWL (m)	Drawdown (m)	Specific Capacity (m^3/h/m)	GWL (m)	Yield (m^3/h)	T m^2/d	K m/d
AL1295	Ain El-Russeifah	248.705	158.66	NA	NA	NA	NA	NA	NA	NA
AL1345	Phosphate No. 7	249.856	157.582	42.6	4.6	16.96	595.4	78	247	2.47
AL1346	Phosphate No. 8	251.865	158.492	46	4.1	14.63	573.0	66		
AL1350	Phosphate No. 10	250.56	157.135	14.8	40	NA	644.2	NA	33.9	0.38
AL1352	RusseifahMunicipality	248.228	158.808	24	4.0	31.5	598	NA	NA	NA
AL2720	Waste Disposal	249.75	157.25	29.6	1.63	40.5	590.4	NA	409	5.18
AL3287	Russeifah Deep	248.5	158.5	96.3	101.2	0.86	503.7	NA	NA	NA
AL1551	RusseifahMunicipality	248.85	158.7	20.9	0.84	142.86	-	120	247	NA
A 105	-	251.409	159.365	NA	NA	NA	574	NA	1673.2	53.12
A 73	-	247.815	158.842	NA	NA	NA	598	NA	2.88	0.21
A 83	-	250.040	158.750	NA	NA	NA	585	NA	NA	NA
AL3385	Russeifah Landfill monitoring well No.2	250.601	158.041	62.9	NA	NA	592.1	NA	NA	NA
AL3386	Russeifah Monitoring well No.3	249.998	157.873	31.1	NA	NA	623.9	NA	NA	NA

Source: El-Naqa et al., 2006

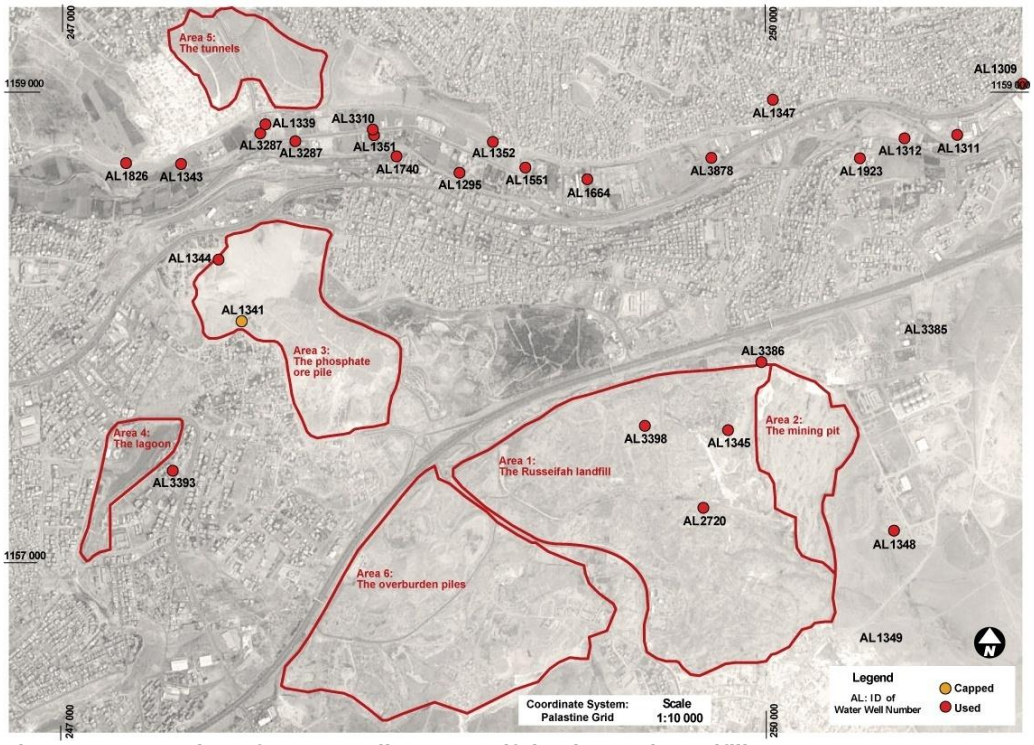

Figure 3-8: Location of Water Wells – Russeifah Mine and Landfill

3.9 Existing Conditions at Russeifah Area 3 Site

3.9.1 Site Description and Environmental Conditions

In Area 3 (Phosphate Stockpile) of the site, the phosphate ore had accumulated into a large stockpile of around 4,500,000 cubic meters, as shown in Figure 3-9 and as can be seen in Figures B1 and B2 in Appendix B, which contains Area 3 3-D and Boundary Images. The pile constitutes mainly of low grade phosphate, covers an approximate area of 350,000 m^2 and reaches up to 40 m high at some locations. In the past, this low grade phosphate ore was hauled from the stock pile and used by JPMC as an additive to the higher grade ore mined in other locations in Jordan. Upon initial storage of the low grade phosphate ore, there was no intention of it remaining in place for such a long time. Therefore, no consideration and precautions were taken to account for side slope integrity; the pile's existing steep slopes can be seen on Figure 3-9 and 3-10.

Figure 3-9: Phosphate Ore Pile

Figure 3-10: Side Slopes of Phosphate Ore Pile

Presently, there are no site access controls. Trucks were seen dumping construction debris illegally at the site and several trucks were also seen removing material from the pile, presumably to be used as filling material at various construction sites.

An additional prominent issue at the site is radiation. A radiological study was conducted by the project team and will be discussed in detail in section 4.5 of this study.

Several site assessment efforts have been performed by the project team for proper identification of site issues. The main site assessment activities were:

- Topographic survey
- Survey of the surrounding land use
- Geotechnical Investigation (Slope Stability)
- Radiation Study

Section 5, Field Investigations, provides a description of each of these site assessment activities in addition to the main results.

3.9.2 Current Operations

There are no official activities taking place at the phosphate ore pile's site at present. Nonetheless, it was noticed that some minor quantities of ore have been removed; these have been assumed to be used as fill at local construction sites. The Area 3 (Phosphate Stockpile) is to undergo rehabilitation with the aim of remediating issues related to both radiation and slope stability.

The MoEnv has, moreover, proposed developing an Eco Park on an area of approximately 100 Donums to the northern part of Area 3. The park is currently in the planning phase and is a collaborative effort between MoEnv and GAM.

3.10 Institutional and Legal Framework

Institutional Framework

By virtue of the *Organization of Natural Resources Affairs Law (12),* the main body responsible for mining activities in Jordan is the NRA. The NRA was formed from many

directorates amongst are Mining, Geology, Water and Irrigation. The President of the NRA is the Minister of Energy and Mineral Resources (NRA official website, 2013).

The role of the NRA includes the suggestion of policies to investigate, develop and exploit energy and mineral resources (NRA official website, 2013). It also includes the exploration and prospecting for mineral resources in the form of conducting geological, geophysical, geochemical, technical and economic studies (NRA official website, 2013). In addition, the NRA adopts plans and programs to administer laws and regulations in the different fields of mineral resources (NRA official website, 2013). The NRA, furthermore, issues the permits and licenses for prospecting explorations, mining, quarrying and mineral rights certificates alongside other responsibilities (NRA official website, 2013).

The main body responsible for environmental legislation and issues in Jordan is the MoEnv. Initially, environmental issues were tied with the Environmental Department in MoMA. This remained so until the formation of the General Corporation for Environmental Protection (GCEP) in 1995 as will be explained in the next section. MoEnv, as it is today, was established in 2003 and was given a mandate to maintain and improve the quality of the environment in Jordan. The MoEnv is therefore responsible for the development of environmental legislation, strategies and policies, including those related to mining activities.

Legal Framework: National Laws, Regulations and Standards

Environmental Protection Law Number (52) of 2006

In 1995, GoJ enacted the first comprehensive *Environmental Law No. (12) of 1995.* Under this law, GCEP was established as a government body and charged with taking care of environmental issues in Jordan. The MoEnv was established in 2003 under the *"Interim" Environment Protection Law No. (1) of 2003,* passed by the GoJ. The law includes 25 articles that handle different environmental issues in Jordan. In 2006, the *"Interim" Environment Protection Law No. (1) of 2003* was ratified to become the *Environment Protection Law No. (52) of 2006.* The law provides legal tools for the management of environmental issues, but it does not explicitly address mining issues. Within the law, MoEnv is the competent authority at national, regional and international levels with regard to all issues and environmental matters.

Article (4) of the *Environment Protection Law Number (52) of 2006* specifies the following responsibilities of MoEnv as related to mining:

> *For the purpose of achieving the goals of environmental protection and the improvement of its various Elements in a sustainable manner the Ministry, in cooperation and coordination with the competent parties, shall carry out the following duties:*
>
> *D- Issuing environmental instructions necessary to protect the Environment and its components and the conditions to establish agricultural, commercial, industrial, housing, mining and other projects and all services relating thereto for compliance therewith and the adoption thereof within preconditions for the licensing or renewal of licensing thereof in accordance with the legal principles in force."*

The article further highlights the role of the Ministry in monitoring and supervision to ensure compliance with environmental specifications and measurements and the set technical standards. It also highlights the role of the Ministry in monitoring and measuring of environmental components and follow-up through scientific centers.

The following regulations as issued by the MoEnv are relevant:

- As per *Clause (H) of Article (3) of the Soil Protection Regulations No. (25) of 2005,* the following is valid:

"The Ministry, in cooperation with the Ministry of Agriculture and any other entity concerned with soil protection shall carry out the following tasks and authorities:

H- To prepare the necessary programs for rehabilitation of quarries and sand mines, and mining areas the waste dumping sites after their reclamation, exploitation and cultivation with the appropriate crops."

- As per *Article (4) of the Regulations for the Protection of the Air,* the following applies:

"The Ministry shall classify the facilities from which Air Pollutants are emitted according to the type and quantity of the emitted pollutants and their effect on the Environment and public health, and shall also determine the areas subject to air pollution and the required monitoring programs, and the necessary procedures to control or prevent environmental damage."

- As per *Clause (A) of Article (5) of the Regulations for the Protection of the Air,* the following applies:

"The Minister, upon the recommendation of the Secretary General, shall form a technical committee consisting of experts from the Ministry and concerned entities, that shall identify those Facilities in existence at the time of the coming into force of these Regulations, and that must realign to become in compliance with the provisions hereof within the period set by it, provided that such period does not exceed five years."

- As per *Article (12) of the Regulations for the Protection of the Air,* the following applies:

"The Ministry, in cooperation and coordination with the Jordan Nuclear Energy Commission, shall take the necessary measures to ascertain the fulfillment of public safety conditions and requirements, radiation prevention, nuclear safety, protection of the Environment, and human health and property from pollution hazards and exposure to ionized radiation."

Natural Resources Affairs Law Number (12) of 1968

From a legal standpoint, the NRA is the responsible body for all that relates to mining. However, with regards to environmental issues it is to consult with the MoEnv which is the main body responsible for environmental laws and regulations as per the *Environment Protection Law No. (52) of 2006.*

The following laws and regulations are relevant to and govern mining activities:

- As per *Clause (b)* of *Article (57)* of *the Organization of Natural Resources Affairs Law Number (12) of 1968:*

"The Authority may maintain, operate and otherwise manage any completed or partially completed project until such project is transferred to, and responsibility for maintenance and operation is fully assumed by the village or municipality or any other public body. The Authority shall not remove the control on any project until sufficient assurances are given that the project will be operated and maintained in a manner to ensure maximum useful life of the project."

- As per *Article (44)* of the same law:

"The holder of an exploration license or mining right shall not appropriate or take water from any lake, river, source or flow of water or canal bordering or passing through licensed land or change its course without the written permission of the President after obtaining the agreement of the owners (if any)."

- As per *Mining Regulation No. (131) for 1966,* the following applies:

"A detailed geological, physical and hydrological study should be carried out for the area in which mining shall take place to include the following:

a- Thickness of the mineral to be extracted, its distribution, gradient, distance from the surface and hardness.

b- Vertical cross sections every 200 meters showing the type of rocks, thickness, hardness and gradient over and under the minerals to be extracted.

c- Cracks and folds which may affect the nature of mining in the area.

d- The highest underground water table which may be found in the area and how far from ground surface.

e- Main water course in the area and the highest level to which the water table may rise in these courses calculated on basis that the rate of annual rainfall is 1000mm."

Radiation Protection Standards

The Jordan Nuclear Regulatory Commission (JNRC) is the body responsible for radiation protection standards in Jordan and typically follows IAEA recommendations on these standards.

The following standards pertain to the IAEA's **Safety Guide for the Management of Radioactive Waste from the Mining and Milling of Ores (No. ES-G-1.2)**:

1.1 "*The radioactive waste generated in mining and milling activities, especially those involving uranium and thorium (U, Th) ores, differs from that generated at nuclear power plants and most other industrial operations and medical facilities. Waste from mining and milling activities contains only low concentrations of radioactive material but it is generated in large volumes in comparison with waste from other facilities. The management methods to be employed are therefore different and will usually involve waste disposition on or near the surface, in the vicinity of the mine and/or mill sites. Furthermore, the waste will contain long lived radionuclides, and this has important implications for its management because of the long time periods for which control will be necessary."*

According to the **Administrative, Legal and Regulatory Framework** section of the same Guide, the following is relevant:

2.8 "*After closure of a mining and milling facility and assurance that the operator has fulfilled its obligations, the regulatory body should ensure that responsibility for the waste is transferred from the operator to an appropriate body with the powers to implement any required institutional control. In many cases, the body having the greatest potential for maintaining these controls is a governmental organization. The regulatory framework should provide a mechanism for this transfer of responsibility. A mechanism should also be provided to ensure that the funding necessary to support institutional control is, and*

continues to be, available. These mechanisms or plans for their establishment should be identified early in the development of operations."

2.9 "*The regulatory body should ensure that a mechanism is established to advise prospective purchasers of land affected by waste from the mining and milling of ores of all relevant details including:*

(a) The nature of the waste and the extent to which the land is affected;

(b) Any restrictions on the use of the land;

(c) Any obligations of the landowner with respect to monitoring, surveillance and maintenance."

Whereas the section on the **Protection of Human Health and the Environment** states:

3.1 "*The management of mining and milling waste is required to include the implementation of measures that will provide acceptable protection of human health and the environment, in compliance with the requirements and recommendations of the IAEA and the International Commission on Radiological Protection (ICRP)."*

3.2 "*The management of mining and milling waste is part of the management of a practice as defined in the BSS and radiation protection considerations are therefore governed by the principles of justification, optimization and dose limitation. The generation and management of this radioactive waste do not need to be justified since this will have been taken into account in the justification of the entire mining practice."*

3.3 "*It has generally been accepted that the application of measures for the radiological protection of human health, in compliance with the requirements of the BSS, is sufficient to ensure that other species are not put at undue risk. Regulatory bodies should develop criteria for their particular situations where this may not be the case."*

3.16 "*A combination of engineering and institutional controls may be used to attain a level of radiological protection that meets the dose or risk constraints determined by the regulatory body. Regardless of the combination of engineering and institutional controls used, there should be reasonable assurance that these controls will remain effective for a specified period. During this period of effective engineering and institutional controls, the closed facility should meet the dose and risk constraints determined by the regulatory body. The period of institutional control should be proposed by the operator in the licensing process and supported by the safety assessment. The proposal should be submitted to the regulatory body for approval. The regulatory body's decision may be based not only on technical grounds, but also on societal considerations, and should be made on a case-by-case basis. The regulatory body should be given reasonable assurance that the controls will remain in place for the required period."*

As per the section on **Strategy for Waste Management**; the following is relevant:

4.2 "*The development of a waste management strategy is usually a complex process that has the aim of achieving a reasonable balance between two, often conflicting, goals: maximization of risk reduction and minimization of financial expenditure. The process is one of optimization of protection in which the available alternatives for siting, design and construction, operation, management of waste streams, and closure are evaluated and compared, with account taken of all associated benefits and detriments and any constraints (such as an annual dose constraint) that are required to be imposed. The characteristics of the alternatives (or options) that should be considered include:*

(a) The radiological and non-radiological impacts on human health and the environment during operation and in the future;

(b) The requirements for monitoring, maintenance and control during operation and after closure;

(c) Any restrictions on the future user of property or water resources;

(d) The financial costs of the various alternatives and the resources available for implementing the alternatives;

(e) The volumes of the various wastes to be managed;

(f) The socioeconomic impacts, including matters relating to public acceptance;

(g) Good engineering practices."

The IAEA Basic Safety Standards (BSS) establish generally applicable dose limits (Table 3-5) for exposure of trained workers and members of the public from radiation hazards resultant from "practices." Practices are defined as "any human activity that introduces additional sources of exposure or exposure pathways or extends exposure to additional people or modifies the network of exposure pathways from existing sources, so as to increase the exposure or the likelihood of exposure of people or the number of people exposed" (IAEA, 1996).

These BSS standards also define the applicability and exemptions for various types for exposures, such as those associated with TENORM. In addition to the BSS, IAEA publishes standards governing specific industry practices, such as, in this case, the mining industry.

The BSS Section 2.5 specifically addresses exposures to natural sources that result in 1) public exposure to effluent discharges or the storage of radioactive waste; or 2) radon exposures to workers at the site (similar to the situation with the Russeifah phosphate ore stockpiles). Such sources are subject to the BSS radiation safety requirements for practices, unless exempted based on the radioactivity content of the ore, or specifically by the regulatory authority, JNRC (IAEA, 1996).

The IAEA publishes specific radionuclide concentrations, below which sources are normally exempt from the regulatory requirements for practices. Subject to the regulatory authority's decision, some sites may be required to demonstrate that the expected doses from the radiation source in question would not exceed occupational and public limits on which the exemption criteria are based (IAEA, 2004).

If not exempted from the BSS requirements, the legal person or entity responsible for the site and associated practice must register or license the site according the regulatory authority. The registrant or licensee is required to establish the technical and managerial structure to ensure compliance with the applicable radiation protection standards.

Survey and sampling results were compared to the IAEA recommended standards for radiation exposures (public and occupational), site management, and decommissioning (see Table 3-5).

Table 3-5: IAEA Recommended Standards for Radiation Protection Limits and Constraints

Exposure Route	Exposure Group	IAEA Recommendations	
Exemption of ores from regulatory requirements	N/A	≤ 1000 Bq/kg	Uranium and/or Thorium (IAEA 2004)
Total effective dose	Public	1 mSv/yr	0.5 mSv/y for sensitive members (e.g., children)
		5 mSv	in one year so long as the average over 5 years does not exceed 1 mSv/yr (IAEA 1996)
Airborne Effluent – Uranium*	Public	3.5×10^{-2} Bq/m^3	average in one year
		1.7×10^{-1} Bq/m^3	average in one year if 5 year average does not exceed 3.5×10^{-2} Bq/m^3 (IAEA 2004)
Radon Exposure	Public	600 Bq/m^3	radon in dwellings
		1000 Bq/m^3	radon in workplaces (IAEA 1996)
Total Effective Dose	Workers	20 mSv/yr	average over 5 years
		50 mSv	in one year
		150 mSv	to the lens of the eye in one year (IAEA 1996)
Occupational Exposure to Airborne Uranium*	Workers	10.4 Bq/m^3	derived air concentration (DAC), average concentration for continuous workplace exposure, 2,000 hour work-year (IAEA 2004)
*Derivation of airborne concentrations of natural uranium corresponding to IAEA dose limits is found in Appendix C of the Radiological Assessment (Annex A) conducted by the project team.			

4.0 METHODOLOGY/PROCESS

The lack of records concerning the nature of the Area 3 phosphate pile necessitated detailed field investigations by the project team. For these investigations, and in proposing remediation alternatives and long term monitoring requirements, the project team used the following methodology:

- Field Investigations:
  - Site Topographic Survey
  - Site Geotechnical Investigation
  - Site Radiological Assessment
- Remedial Action Planning
  - Site Issues
  - Remedial Objectives
  - Proposed Remediation Alternatives
  - Cost Estimate

The following sections explain the application of the methodology to the Russeifah Area 3 (Phosphate Stockpile) site.

5.0 FIELD INVESTIGATIONS

This chapter provides an overview of the field investigations carried out by the project team at the Russeifah Area 3 (Phosphate Stockpile) site.

5.1 Topographic Survey

A topographic survey was performed in October 2011, as presented in Appendix C. The survey data was mainly used to design new site grading plans and to estimate the total volume and earth work needed. The total area that the site covers is around 350,000m^2 and consists of around 4,500,000 m^{3}of ore material.

5.2 Survey of Surrounding Land Uses

Studying the surrounding land use is important for evaluating options for the remediation of the phosphate ore stockpile in the local area. Also, surrounding land use is important to consider when developing a new master plan for the area.

Since the mid-1930s the Russeifah area has seen a significant increase in population, with increases in the number of residences, as well as commercial and light industrial business. Figure 5-1 shows the relationship of the various Russeifah Areas and the existing land uses of their surroundings.

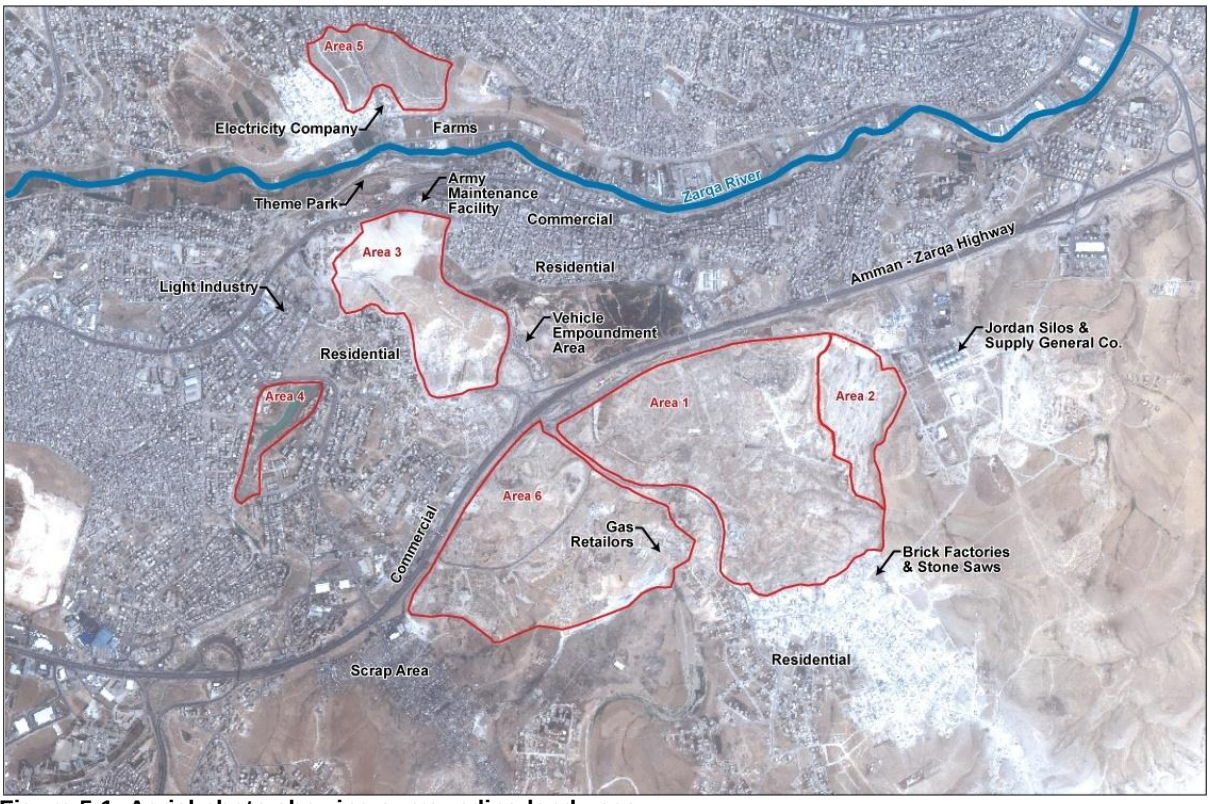

Figure 5-1: Aerial photo showing surrounding land uses

5.2.1 Zarqa River

The Zarqa River is located just to the north of Area 3. The river generally flows to the north before heading west and finally discharging into the Jordan River at an elevation of 1,090 m lower than its origin. The river's summer base flow is approximately 2 to 3 MCM/month and

rises to 5 to 8 MCM/month during the winter. The total basin area of the river is 3,900 $km^2$and is considered the largest in Jordan (See Figure 5-2).

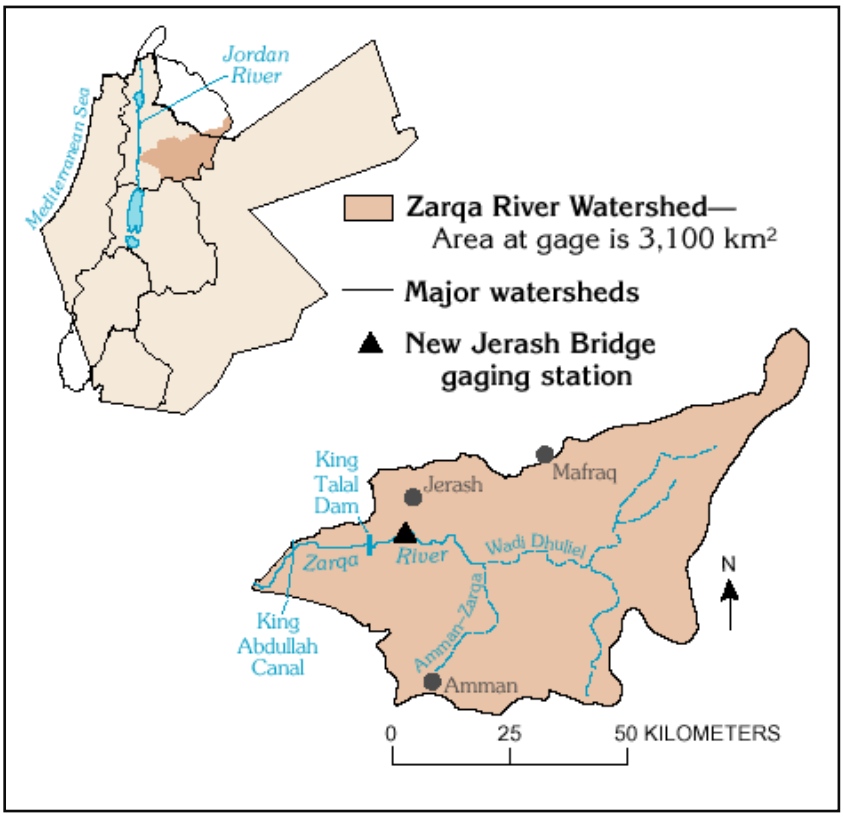

Figure 5-2: Zarqa River watershed
(Adopted from Executive Action Team (EXACT), Multilateral Working Group on Water Resources)

Within the Russeifah Phosphate mining area, the Zarqa River lies to the north of the phosphate ore pile. The river is dry most of the year, but when it flows, the major direct water uses are crop and grazing land irrigation in addition to livestock watering.

5.2.2 Amman Zarqa Highway

The Amman-Zarqa highway crosses midway through the Russeifah phosphate mining area. The highway is located north of Areas 1, 2 and 6 and south of Areas 3 and 4, and it is considered a primary access route in Jordan.

5.2.3 Light Industrial Areas / Commercial (Block and Stone / Car Maintenance)

Several light and heavy industries are found near the phosphate mining areas; these include the Jordan Silos and Supply General Co. located east of the Area 2 (Pit), brick factories and gas storage area are located south and west of the Area 1 (Landfill). Light industries dedicated to car maintenance are also found west of Area 3 (Phosphate Stockpile).

5.2.4 Scrap and Car Impoundment Area

A car impoundment area is located south of Area 3 (Phosphate Stockpile). A recycling and scrap area is located southwest of Area 6 (Overburden Pile).

5.2.5 Residential Areas

The Zarqa governorate is considered the third largest governorate, with population approaching 910,800 in 2010 (Jordanian Department of Statistics, 2010). In addition, the city of Russeifah within the governorate is considered one of its most heavily populated cities and ranks as the fourth largest city in Jordan. Currently, several residential areas surround the Russeifah phosphate mining area. As can be seen in Figure 5-1 (above), these residential areas are found south of the landfill area, north of Amman Zarqa highway, south of Zarqa River and west and east of the phosphate ore.

5.3 Geotechnical Investigation

The project team performed a geotechnical investigation at the site via ACES, a specialized geotechnical firm in Jordan. The purpose was to investigate and determine the subsurface conditions and to carry out slope stability analysis for the phosphate stockpile. The purpose further included determining the physical and chemical properties of the ground materials, to provide sufficient geotechnical parameters for the design and construction of the proposed project and slope stability parameters.

Nineteen boreholes were drilled at the site of Area 3 between 25 August 2013 and 24 September 2013 to obtain disturbed and undisturbed samples and to carry out the required and appropriate lab tests. The boreholes were drilled at depths ranging from 5.0 m to 40.0 m below the existing ground surface. These can be seen in Figure 5-3 and are presented in Table 5-1.

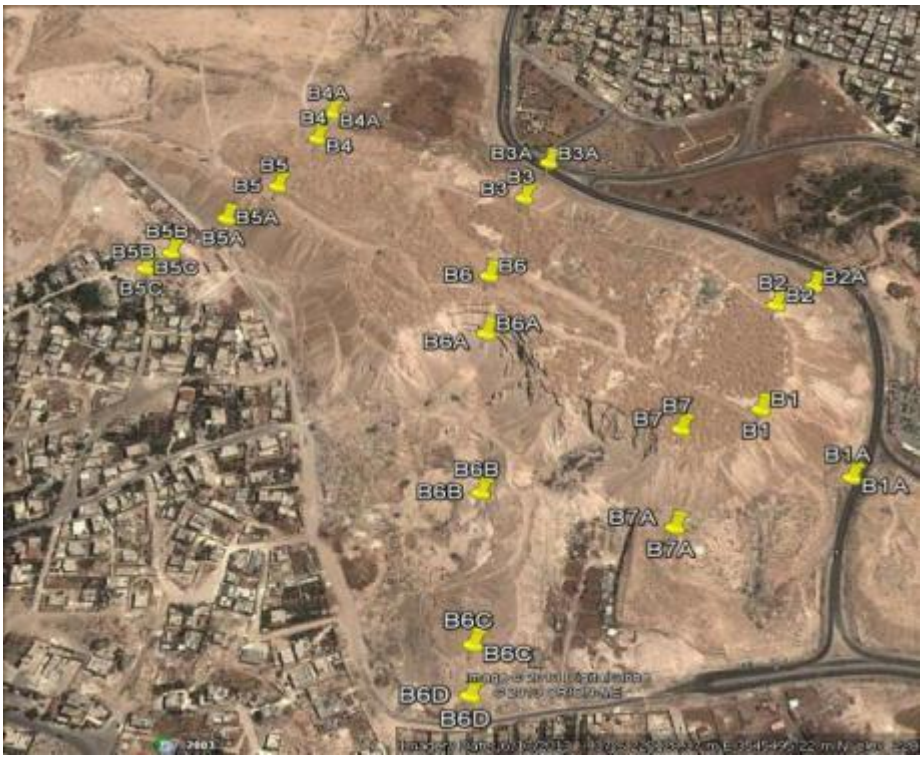

Figure 5-3: Borehole locations, Area 3

Table 5-1: Area 3 Borehole Details

BH No.	Elevation (m)	Coordinates		Depth (m)
		Northing	Easting	
B1	705.50	32.01064	36.03902	40
B1A	664.50	32.01015	36.03976	10
B2	705.50	32.01167	36.03899	40
B2A	671.07	32.01187	36.03957	10
B3	702.50	32.01274	36.03687	30
B3A	668.25	32.01321	36.03712	10
B4	703.00	32.01337	36.03473	30
B4A	676.20	32.01378	36.03502	10
B5	698.00	32.01289	36.03440	30
B5A	675.50	32.01248	36.03401	5
B5B	689.80	32.01247	36.03335	15
B5C	681.00	32.01196	36.03336	10
B6	707.00	32.01189	36.03656	40
B6A	665.00	32.01112	36.03658	10
B6B	663.50	32.01013	36.03657	5
B6C	680.50	32.00863	36.03650	20
B6D	670.00	32.00824	36.03643	5
B7	705.00	32.01052	36.03829	35
B7A	674.00	32.00963	36.03823	5

Six test pits were excavated along the slope profiles with the purpose of visually inspecting the shallow subsurface conditions and assessing the general characterization of the encountered ground materials. These were dug to approximate depths of 2 m below the existing ground surface. Details of the excavated test pits can be seen in Table 5-2.

Table 5-2: Area 3 Test Pits

Test Pit No.	Elevation (m)	Coordinates		Depth (m)
		Easting	Northing	
TP1	665.5	36.039898	32.01053	2
TP2	706.0	36.03870	32.01191	2
TP3	697.5	36.03585	32.01310	2
TP4	677.7	36.03687	32.01046	2
TP5	705.5	36.03576	32.01190	2
TP6	686.5	36.03330	32.01215	2

5.3.1 Geotechnical Testing

Both In-Situ and laboratory testing were conducted. Following is a short description of each.

In-Situ testing consisted of the following:

- Standard Penetration Tests (SPT): SPTs were conducted in all the drilled borehoels in the fill layer with the purpose of obtaining the approximate dynamic resistance of the ground materials. The test was performed in accordance with BS 1377:90: Part 9, clause 3.3.

- Field Density Tests: Six field density tests were performed at the test pits' locations in the fill deposits and using the sand-cone method in accordance with ASTM D 1556.

Laboratory Testing:

Laboratory tests were performed on samples obtained from the excavated test pits to identify the physical and mechanical properties of the encountered materials:

- Classification and Index Tests: Moisture content, specific gravity, bulk density, and particle size distribution.

- Strength Tests: Uniaxial compressive strength, point load strength and direct shear.

- Chemical Tests: pH, sulfate, chloride and carbonates organic matter.

These tests were conducted in accordance to the relevant American Society for Testing and Materials (ASTM) standards. Table 5-3 outlines the tests and relevant standards. The results can be found in Annex B.

Table 5-3: Tests conducted and corresponding Standards

No.	Test	Standard No.	Title of Standards
1.	**Classification and Index Tests**		
1.1	Moisture Content	D 2216-05	**Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass**
1.2	Particle Size	D 422-63 (2007)	**Standard Test Method for Particle-Size Analysis of Soils**
1.3	Specific Gravity	D 854-06	**Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer**
1.4	Bulk Density	D 7263-09	**Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens**
2.	**Strength Test**		
2.1	Direct Shear	D 3080-04	**Standard Test Method for Direct Shear Test of Soils under Consolidated Drained Conditions**
3.	**Chemical Tests**		
3.1	pH Value	BS 1377: Part 3, Clause 9, 1990	**Determination of the pH Value**
	Sulfate Content	BS 1377: Part 3, Clause 5, 1990	**Determination of the Sulfate Content of Soil and Groundwater**
	Chloride Content	BS 1377: Part 3, Clause 7.3, 1990	**Determination of Acid-Soluble Chloride Content**

The detailed geological description of the ground materials can be found in Annex B. These ground materials are as follows according to the order in which they were encountered (more details are found in Annex B):

- Fill Materials (Gravel and Cobbles)
- Fill Materials (Sand size)
- Fill Materials (Mixture)
- Fill Materials (Silty Clay)

- Fill Materials (Silty Clay Mixture)
- Fill Materials (Chalky Marl)
- Garbage Materials
- Alluvial Deposits
- Intercalated Materials (Natural Bedrock)
- Chalky Marlstone (Natural Bedrock)

With the exception of borehole B2A, no cavities were encountered in any of the other boreholes down to the drilled depths in Area 3. However, small to medium voids were encountered and caused loss of air during drilling. Furthermore, no groundwater was encountered in any of the boreholes drilled.

5.3.2 Slope Stability Analysis

Slope stability analyses were carried out for typical representative high slope areas at the site. The analysis considered both static and dynamic conditions of the side slope and took into account material types, strength properties and the geometry of the current and suggested slopes. Exact details of the analysis can be found in Annex B. Table 5-4 displays the detailed slope stability evaluation of the current conditions for seven representative side slopes. The safety criteria dictated was as follows: “Factor of safety for potential failure below 1.2 is to be considered not safe.”

Table 5-4: Existing Conditions

Section/Profile	Max. Slope Height (m)	Slope Inclination* H:V	Min. Factor of Safety
B1-B1A	46	1.51:1	0.951
B2-B2A	45	1.50:1	0.928
B3-B3A	29.5	1.45:1	1.124
B4-B4A	23	1.54:1	1.24
B5-B5A	20	1.50:1	1.324
B6-B6A	40	1:1	0.606
B7-B7A	30	1.4:1	1.202

*The slope inclination is the current conditions existing at each area

Based on the safety criteria and the results presented in Table 5-4, it can be seen that the factors of safety are, for the most part, below the acceptable limits thus making most sections not safe. Further details are presented in Annex B.

Two scenarios were proposed and simulated for slope stability to stabilize the slopes:

Flatten the slope with 2H:1V side slope inclination with benches. This involved remodeling the slope area with a milder slope of 2H:1V with an 8m wide bench and 23m back slope height. The results of this stability analysis (minimum factor of safety) are displayed Table 5-5 below. Further figures and the analysis reports can be found in the Geotechnical Report in Annex B.

Table 5-5: Flatten the Slope with 2H:1V Side Slope Inclination with Benches

Section/Profile	Max Slope Height (m)	Slope Inclination H:V	Min Factor of Safety	
			Static	Dynamic
B1-B1A	46	2:1	1.353	0.965
B2-B2A	45	2:1	1.271	0.927
B3-B3A	29.5	2:1	1.194	0.927
B4-B4A	23	2:1	-	-
B5-B5A	20	2:1	-	-
B6-B6A	40	2:1	1.314	0.965
B7-B7A	30	2:1	1.627	1.163

Support the Side Slope by Geo-Grid. This involved remodeling the existing slope of approximately 1.5H:1V, which is the condition in most sections, using a protecting wall composed of 9.0m width geo-grid wall inclined at 65 degrees. The parameters used for the geo-grid layer are as displayed in Table 5-6 next:

Table 5-6: Material Properties used in the Stability Analysis

Material Type	Unit Weight (kN/m^3)	Shear Strength Parameters	
		C (KPa)	Ø (Degrees)
Geo-Grid	18	100	35

The results of the stability analysis (minimum factor of safety) are as presented in Table 5-7 below. Further details and figures can be found in the Geotechnical Report in Annex B.

Table 5-7: Support the Side Slope by a Geo-grid

Section/Profile	Max Slope Height (m)	Slope Inclination H:V*	Benches (m)	Min Factor of Safety	
				Static	Dynamic
B1-B1A	46	1.51:1	22	1.319	0.997
B2-B2A	45	1.50:1	20	1.392	1.091
B3-B3A	29.5	1.45:1	25	1.637	1.281
B4-B4A	23	1.54:1	-	1.536	1.218
B5-B5A	20	1.50:1	-	1.918	1.540
B6-B6A	40	1:1	27	1.556	1.219
B7-B7A	30	1.4:1	16	1.487	1.142

5.4 Radiological Assessment

A radiological assessment of the phosphate ore stockpile was conducted by the project team to preliminarily determine the range of radiological risks associated with the radioactive material present in the Phosphate Ore Stockpile site.

5.4.1 Need for Radiological Assessment

After review of available reports and documents, data collection, field visits, meeting with relevant authorities, and discussions with the stakeholders, it was determined that the Area 3 (Phosphate Stockpile) contains measurable quantities of radioactive material. This was in line with research on worldwide mining of phosphate ore, which indicates that it is normal for radioactive elements to be present with phosphate ore. This indicated the need for a thorough investigation of the nature and levels of the radioactivity present in the phosphate ore to determine the potential risks that may be encountered by exposure to the ore, and to determine the actual risks from dust during the remediation of the pile (plus the method of remediation).

5.4.2 Radiological Assessment Components

The assessment evaluated the separate contributions to radiological exposure of workers and nearby residents contributed by: maximum rates of direct radiation from surfaces; inadvertent ingestion of contaminated soils; and predicted inhalation of fugitive airborne dusts from the Russeifah site.

The radiological assessment consisted of the following components:

- **External Radiation Survey** to assess the external dose rates throughout the site including background radiation

- **Gamma Walkover Survey** to map the relative external radiation exposure contributions from TENORM surface soil concentrations present throughout the site
- **Soil Sampling and analysis** to:
    - Correlate the survey instrument response to surface radioactivity levels
    - Characterize the radionuclide concentrations and properties of the materials found on the site, including the stockpiles and any surrounding contamination
- **Environmental Air Sampling** using high volume air samplers to assess airborne concentrations of resuspended TENORM
- **Personal Air Sampling** using lapel samplers to measure breathing zone airborne TENORM exposure to workers during these construction activities simulated at an Ore Loading area
- **Radon Sampling** to characterize radon emanation rates present in the different previous use areas and characterize geologic features throughout the site.
- **Air Modeling** of potential worst case exposures from fugitive dusts
- **Radiological dose and related risk (screening) analysis** to integrate the various measures of exposures and doses so that they can be compared with dosimetric and risk guidance commonly utilized to judge the current and potential future status of a TENORM-contaminated site

The site was broken into the following areas for evaluation based on the different conditions found in each; more details can be found in the complete Radiological Assessment report attached in Annex A:

1. Ore Stockpile Area: this area consists of the stockpiled, unprocessed ore material.
2. Fine Aggregate Processing Area: this area consists of piles of processed ore materials.
3. Park Area: this area constitutes of compacted ore material.
4. Background Area: the background area for external exposure measurements was a field area approximately one kilometer east of the site.

5.4.3 Radiological Assessment Main Conclusions

Final results indicate that the average uranium concentration of the ore material found at the Russeifah Area 3 site is greater than the IAEA recommended criteria for exemption from regulatory controls. The dose assessments conducted for exposure scenarios of likely receptors indicate the possibility that workers and members of the public could receive doses up to 8 mSv/yr (not including contributions from radon,) which is considered high enough to warrant continued review and potential improvement.

Assessment of individual facilities is required to evaluate the radon exposure to workers and residents. Such exposures to workers in facilities at Russeifah Area 3 are subject to the requirement of protective practices according to IAEA standards.

The assumptions used in the site radiological survey measurement and preliminary risk assessment study are intentionally conservative. Future users of the site should compare actual planned site operations to the scenarios modeled in the radiological survey report to gauge relative predicted dose. In addition, the complementary air modeling performed to help interpret how typical the measured results might be, compared with other days and wind conditions led to further prediction of long-term estimates of total exposures to nearby public areas, as well as on-site work areas.

Air modeling results suggest that several local subareas may experience concentrations that are significantly higher than those measured either directly or through analysis of samples acquired in the preliminary field testing and soil radiation measurement phases of the

assessment study. According to IAEA Safety Guides, both public and worker radiation exposures at Russeifah Area 3 would likely be subjected to the requirements of protective practices. This is due to the potential dose resultant from worker and public exposures to airborne dusts and radon originating from the ore material that comprise the site.

Based on the survey and sampling results from Russeifah Area 3, any development on the site must take into account radiation safety measures to protect future site users from prolonged exposure risks. The data analyses and the comparative modeling of the potential addition of inhalation exposures are sufficient to conclude that the associated risks should not be dismissed, under IAEA standards, without further consideration by the responsible regulatory body.

The outdoor levels of radon were comparable to those in the general U.S. EPA guidelines for uranium-contaminated tailings materials, but this guide is not specifically applicable to the Russiefah site. The related dose contribution for radon present in indoor workplaces has not been considered in detail in the present study, because none of the data acquired was directed toward assessing indoor air levels. Therefore, this source of additional exposure may need to be considered further in the future, for both on-site workers and residents near site boundaries.

The detailed and tabulated results can be found in the complete Radiological Assessment report attached in Annex A.

6.0 REMEDIATION ACTION PLANNING

6.1 Site Issues

The main site issues identified after the completion of field investigations are:

- Radiation exposure to site users through direct exposure
- Radiation exposure to nearby residences through dust blowing with the wind
- Physical stability of the pile because of the steep and unstable side slops
- The random nature of the site topography is not suitable for site development

6.2 Remediation Objectives

To remediate the site issues presented above, the following objectives were identified:

- Stabilize the slope of the pile so it will be stable in static and dynamic conditions
- Cover the pile material to reduce risk of radiation exposure and reduce dust migration to nearby areas

7.0 PROPOSED REMEDIATION ALTERNATIVES FOR RUSSEIFAH AREA 3 (PHOSPHATE ORE PILE) REHABILITATION

Three alternatives were analyzed:

- Remove the pile completely
- Sieve the pile onsite
- Leave the pile where it is

7.1 Complete Removal of Pile

Ideally, the land under the phosphate ore pile (Area 3) should be returned to its natural undisturbed state. To achieve this aggressive objective of complete pile removal, a tremendous amount of excavation and transportation would be required. Currently, there are two possible destinations to which the ore pile could be relocated. These destinations are the phosphate mines in Hassa, located in the south of the Kingdom, or the nearby Russeifah Area 2 (Pit). This pit area is currently being used by GAM as a construction and demolition (C/D) landfill. A recent survey showed that the pit remaining capacity is large enough to accept the majority of the Area 3 (Phosphate Pile). The remaining pit capacity was found to be more than 5.5 million m^3, whereas the total pile volume is approximately 4.5 million m^3.

7.1.1 Area 3 Phosphate Ore Pile Volume Estimation

The entire Area 3 site was surveyed in October 2011, and the resulting topographic map is presented in Appendix C. The survey results were also used to estimate the volume of the pile by using Civil 3D software by Autodesk. Area 3 was found to be divided into three sub piles, with a total ore volume estimated to be 4.5 millionm$^{3.}$

7.1.2 Limiting Factors

The major limiting factor for Area 3 (Phosphate Pile) removal is expected to be the road traffic capacity and cost of removal. To estimate the time needed for complete removal of the pile to the Pit location, it was assumed that the road capacity could on average accommodate an additional 25 trucks per hour. This means that the daily removal would be approximately 2000 m^3 per day. Therefore, the total time required to remove the pile is around 2,250 working days, or 9 years. Even if it were feasible to increase the average to 50 trucks per hour, approximately 1,125 working days, or 4.5 years, would be required. Work could be done at night, but in all conditions, pile removal will create tremendous amounts of dust which as concluded from the Radiological study is harmful as it contains radiation exposure to the neighboring areas. Therefore, the alternative of completely removing the pile was eliminated.

7.2 Onsite Sieving of the Pile

Onsite crushing and sieving of the pile makes it possible to extract the phosphate ore and use the remaining crushed aggregate for construction projects. This alternative is also expected to generate tremendous amounts of dust and is thus also unlikely to be recommended. Dust control for this type of activity requires large amounts of water, which are not readily available at the site. Also, the generated aggregate should be carefully controlled because of its radioactive nature, and it should not be used for house construction.

This remediation alternative is nonetheless an option for the phosphate company, if they decide they wish to use the ore. As explained above in Section 3.2, in the discussion of

entities responsible for the site, at the request of the Jordanian Prime minister's office, a technical committee was formed in August 2013 to study the issues related to the phosphate areas. The committee agreed on the following recommendation for Russeifah Area 3:

The JPMC will be given the opportunity to use the phosphate ore in the pile but must adhere to strict environmental dust control conditions. JPMC would be required to prepare a technical study for the rehabilitation of the phosphate piles and present it to MoEnv for approval. This study is to include the following:

- A description of the technical and environmental mechanism for utilizing the ore material in addition to the time frame for implementation.
- The statement of financial returns from the proceeds of the utilization which should be allocated to rehabilitate the area of Russeifah.

If JPMC does not agree to conduct the effort according to the environmental provisions set out by the MoEnv concerning dust control and environment management during project implementation, MoEnv has the right to decide on the fate of the pile, and they are anticipated to make that decision in accordance with the recommendations of this FA.

If the JPMC does not conduct the environmentally safe removal of the pile, then the pile will need to stay where it is, but it should be remediated as discussed in the following section.

7.3 Pile to Remain in its Location

Leaving the pile in its place will require that the following components be considered, at a minimum:

- Re-shaping quantities and final design (Cut & Fill)
- Slope stabilization
- Storm water management
- Soil cover to protect from the naturally occurring radiation

Two alternatives were studied:

- Stabilization by grouted riprap (loose stones or rubble held together by a mortar or paste)
- Stabilization via geo-grid (a synthetic material used to reinforce soils and similar materials)

7.3.1 Stabilization by Grouted Riprap

Stabilization by grouted riprap includes the following steps:

- Flatten the pile sides to a 3:1 (H:V) side slope
- Cover the inclined side surface with grouted riprap
- Create 3-m wide terraces every 10 m of elevation of the side slopes and cover those with natural clay soil material
- Flatten the top of the pile to make it suitable for development
- Manage stormwater through channels and chutes.

This alternative achieves radiation protection by covering the inclined side surface with grouted riprap and covering the top grading levels and berms with 1 m of natural clay soil.

The area at the top that can be used after grading is around 66,300 SM. The amount of soil that will have to be re graded is approximately 1.25 million CM. Feasibility-level design drawings can be found in Appendix D.

7.3.2 Stabilization by Geo-Grid

Stabilization by geo-grid includes the following steps:

- Create geo-grid-reinforced side slopes at an angle of 65 degrees
- Create one 30-m wide terrace half way up the vertical distance of the pile and cover that with natural clay soil material
- Flatten the top area of the pile to make it suitable for development
- Manage stormwater through channels and chutes

This alternative achieves radiation protection by covering the top grading levels and the 30-m wide berm with 1 m of natural clay soil.

The area at the top of the pile that can be used for development is around 116,630 SM. The amount of soil that will have to be re-graded is around 1.38 million CM. Feasibility level design drawings can be found in Appendix D.

Table 7-1: Comparison of Area 3 Remediation Alternatives

Parameter	Option 3: Pile to remain in its Location	
	Alternative 1: Grouted Riprap	**Alternative 2: Geo-Grid**
Slope Stabilization	Achieves sufficient slope stabilization	Achieves sufficient slope stabilization
Radiation Protection	Achieves radiation protection	Achieves radiation protection
Environmental Aspects during Construction	Require slightly less dust control (since less earth is moved)	Requires slightly more dust control (since more earth is moved)
Cost	$12,676,100	$17,974,700
Area available for development uses(*)	66,300 SM	116,630 SM

***Area on top of pile after cover would be available for restricted site development activities such as public parks or similar and should be under the supervision of the JNRC

As shown in this table, using grouted riprap will cost less than using geo-grid but will yield a smaller area to be developed on top.

8.0 COST ESTIMATE

This section includes the cost estimate for the alternatives proposed for remediating the phosphate ore pile (Area 3). It is important to note that the scope of work does not cover the infrastructure and actual redevelopment of the area. The scope covers only physical stability of the side slopes and remediation of the site from an environmental risk perspective.

Alternative 1 Grouted Riprap
This alternative consists of reshaping of the pile's side slopes to 3:1 (H:V), covering the side slopes with grouted riprap, flattening the top area of the pile after reshaping and then covering it with red clay soil.

Project elements included in the estimate of this alternative are:

- Earthwork for Pile reshaping
- Grouted riprap to cover the side slopes
- Covering the top area with red clay soil
- Storm water drainage
- Retaining wall to protect existing dwellings

The total cost of this alternative comes up to $12,676,100; details can be seen in Appendix E. A variation of this alternative, reshaping the side slopes to 2:1 (H:V), was also considered. The 2:1 alternative can be considered stable technically as per the geotechnical investigation; however, due to the lack of documentation, the randomness of the pile, and the radioactive nature of the ore material, it was determined to go with the more conservative approach of 3:1. The cost of the 2:1 alternative was estimated for comparison and was found to be $ 11,876,100.

Alternative-2 Geo-Grid Reinforced Embankment
This alternative consists of reshaping the pile's side slopes and stabilizing it by reinforced embankment at an incline of 65 degrees by geo grid, flattening the top area of the pile after reshaping, and covering the top area with red clay soil. This alternative also includes a 30-m bench at mid-height of the side slope. The use of the bench is for cost reduction in the geo-grid and for utilization by site users if site owners wish to do so.

Project elements included in the estimate of this alternative include:

- Earthwork for pile reshaping
- Installation of the geo grid reinforced embankment
- Covering the top with red clay soil
- Storm water drainage
- Retaining wall to protect existing dwellings

The total cost of this alternative is $17,974,700; details can be seen in Appendix E. A variation of this alternative, using a smaller bench of 5 m instead of 30, was also considered. The 5-meter bench is a stable and low cost alternative but does not allow development at the bench. The final bench width could by any width more than 5 for an economic geo-grid design. The cost of the 5 meter bench alternative was estimated to be $ 17,922,700.

9.0 SUMMARY

The 4.5 million CM phosphate pile at Russeifah that has been in its place for more than 20 years has been found to have negative environmental impacts associated with its dust emissions and physical side slope stability. These findings were based on detailed field investigations performed by the project team, including a topographic survey, a geotechnical field investigation and slope stability modeling, and a radiological site assessment. The environmental impacts of the pile affect the area of the site itself in addition to neighboring areas and should therefore be controlled.

Removing the pile completely was found not to be practical; the more practical solution was found to be leaving the pile where it is, with modifications, including:

- Either flatten the side slopes to 3:1 (H:V) and cover the exposed sides with grouted riprap, or stabilize the side slopes with geo-grid at a 65 degree angle.
- Cover the entire top area with natural clay soil
- Control stormwater

A cost estimate was prepared for each of the proposed alternatives above; the grouted riprap alternative was the lowest cost alternative and is therefore the recommended alternative.

Site remediation as proposed in this report can make the site safer for the neighboring areas and may allow the site to be developed into something useful such as a public park or similar. It is important to note, however, that the uranium concentrations measured on the site were above the limit set in the regulatory requirements, which means that even with the remediation controls proposed in this FA, the Jordan nuclear regulatory commission should be involved during site operation in the long run.

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APPENDICES